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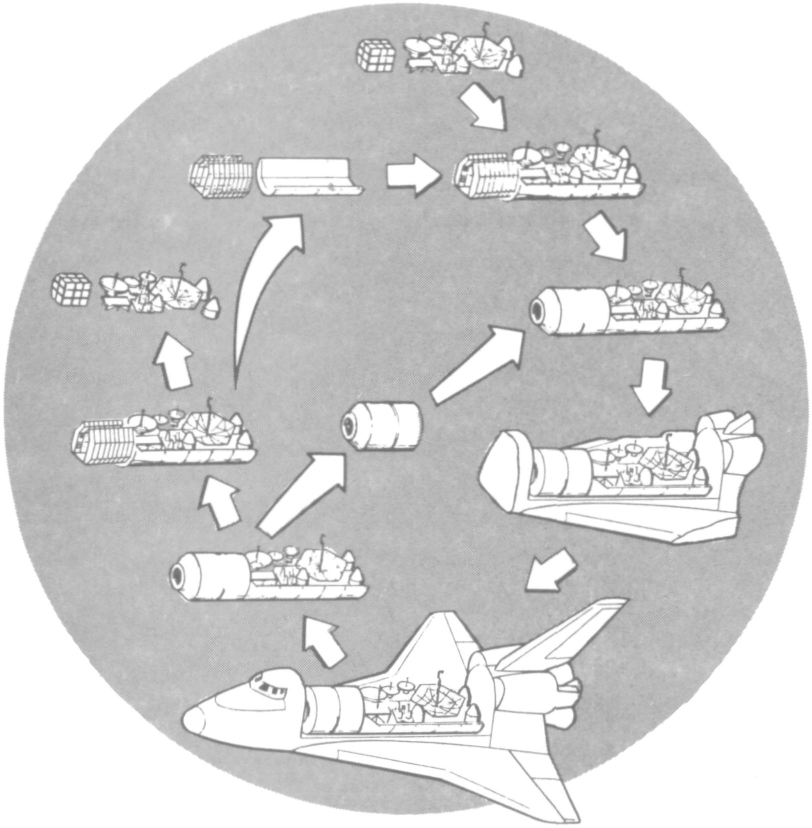

SPACELAB USER IMPLEMENTATION ASSESSMENT STUDY

Volume II

Concept Optimization

CR-132581

February 1975

Rockwell International
Space Division
12214 Lakewood Boulevard
Downey, California 90241

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FINAL REPORT

SPACELAB USER IMPLEMENTATION ASSESSMENT STUDY

Volume II
Concept Optimization

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FEBRUARY 1975

SUBMITTED TO
LANGLEY RESEARCH CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

Space Division
Rockwell International

FOREWORD

The Spacelab User Implementation Assessment Study was conducted to assess and minimize the capital investment of the National Aeronautics and Space Administration for the integration and checkout of Spacelab payloads such as Langley's Advanced Technology Laboratory. The study was conducted by the Space Division of Rockwell International Corporation under Contract NAS1-12933 for the Langley Research Center. Mr. F. O. Allamby was the technical study manager for the Langley Research Center. In addition, this study received agency-wide guidance and evaluation from the Steering Group for Payloads Operations Concept Studies, directed by Mr. W. O. Armstrong, to maximize the objectivity and applicability of the study data.

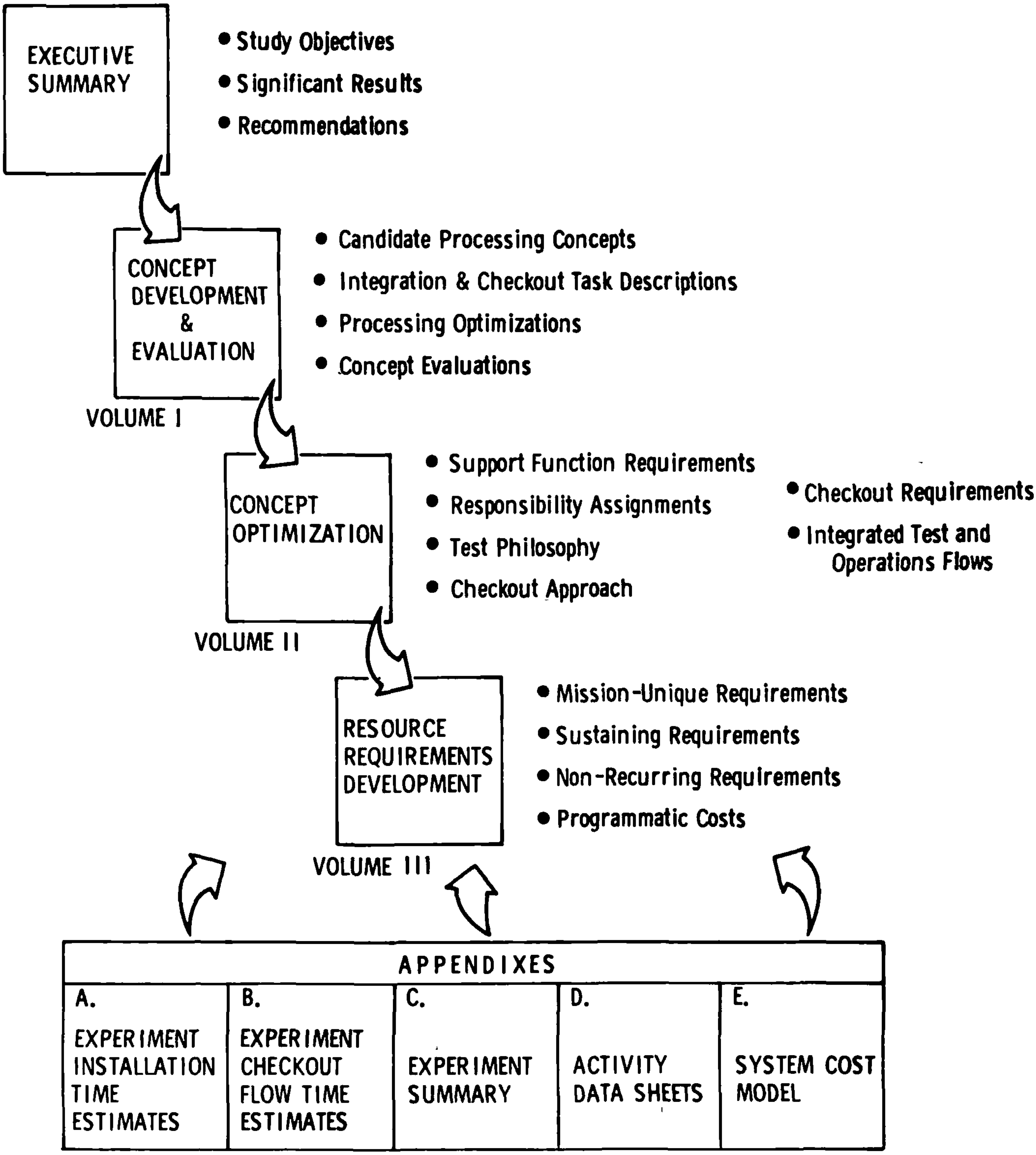
The final report consists of an executive summary and four technical volumes as illustrated in the accompanying figure. A succinct summary of the study is presented in the executive summary. Three of the four technical volumes present the analyses and trades performed during the course of the study. The fourth volume contains five appendixes, which delineate detailed data pertaining to the installation and checkout of Spacelab payloads such as the ATL, and a computer cost model utilized in the compilation of programmatic resource requirements. The contents of the volumes are described below.

EXECUTIVE SUMMARY

- Study overview--objectives, study approach.
- Synopsis of development of candidate processing concepts--complete Spacelab and pallet-only configurations.
- Summary of integration and checkout optimizations--checkout approach, ground operations processing cycle, personnel, ground support equipment and facility requirements.
- Programmatic costing--mission-unique, sustaining, and non-recurring cost estimates for required personnel, material, travel, documentation, ground support equipment, and facilities.
- Concept evaluations--flight-rate sensitivities and concept applicabilities.

VOLUME I. CONCEPT DEVELOPMENT AND EVALUATION

- Complete Spacelab processing concept development.
- Pallet-only processing concept development.



Study Reports

- Results of study optimizations in the areas of checkout requirements, simulator utilization, and configurational changes.
- Flight-rate sensitivities--flight hardware, GSE, facility, and personnel.
- Concept evaluations--integration center/launch site co-location, support module cognizance, WTR implications, general applicability, recommended ATL approach.

VOLUME II. CONCEPT OPTIMIZATIONS

- Supporting functions--development, definitions, and responsibility assignments. Identifies potential software applications.
- Test requirements--checkout approach and requirements, test philosophy, and environmental test requirements.
- Test and operations sequence--development of functional flows, detailed operations, activity data sheets, and integrated flows for both the complete Spacelab and pallet-only processing concepts.

VOLUME III. RESOURCE REQUIREMENTS DEVELOPMENT

- Requirements for mission-unique, sustaining, and non-recurring resources--includes personnel, travel, transportation, material, documentation, GSE, and facilities.
- Programmatic costing--presents cost estimates for all resource requirements.
- Cost-risk analysis--parametric evaluation of deletion of vibra-acoustic, thermal-vacuum and repeat functional tests.

VOLUME IV. APPENDIXES A, B, C, D, AND E

- *Appendix A. Experiment Installation Time Estimates* - Time estimates of the required experiment installation activities including (1) physical installation of experiment hardware in a rack, igloo, or on a pallet; (2) performance of electrical bonding checks; (3) complete mechanical interconnection including fluid and electrical lines; and (4) performance of end-to-end continuity checks between the experiment connector and the interface connector at the experiment module/pallet, support module/experiment module or igloo interfaces.

- *Appendix B. Experiment Checkout Flow Time Estimates* - The general experiment checkout flow plus the time estimates for

each individual experiment in the ATL experiment complement. These time estimates detail the time required for:

- Equipment setup and activation, including controls and display equipment.
- Verification of the operation of mechanical devices of both pallet and rack-mounted sensors and auxiliary equipment.
- Verification of data processing/recording equipment and instrumentation concurrent with checkout of the experiments.

• *Appendix C. Experiment Summary* - A summary of the requirements and equipment utilized for each experiment included in the study. The experiments are listed by discipline.

  - Navigation
  - Earth Observations
  - Physics and Chemistry
  - Microbiology
  - Environmental Effects
  - Components and Systems Testing

  The summary for each experiment includes the objectives or purpose, the description of the equipment utilized, the operation of the equipment, and the physical parameters of mass properties and equipment installation location (pallet, rack, igloo).

• *Appendix D. Activity Data Sheets* - Detailed definitions of the test operations associated with each activity defined in the expanded functional blocks (detailed functional flows). The activity data sheets describe the operations involved and the resources utilized to accomplish the processing cycle. They cover the entire cycle from initial experiment installation through the various integration levels (Experiment, III; Spacelab, II; Orbiter Cargo, I), and the refurbishment of the pallets, racks and/or igloos, following the completion of the mission.

• *Appendix E. System Cost Model* - Description of computer cost model utilized in the study to compile the derived resource requirements into mission-unique, sustaining, and non-recurring cost categories.

Within each volume, the term "concept" is used repeatedly and data are presented with respect to Concepts I through VIII. The concepts referred to pertain to alternate integration and checkout approaches for both the complete Spacelab (support module, experiment module, and pallet) and the pallet-only Spacelab configuration. The following two tables define, in general terms, each of the eight processing concepts that were definitized in this study.

Complete Spacelab Processing Concepts

CONCEPT	OWNER			INTEGRATION SITE	
	SM/EM SHELL*	RACKS & RACK SETS	PALLET	EXPERIMENT EQUIPMENT	SPACELAB
I	IC	IC	IC	IC	IC
II	LS	IC	IC	IC	LS
III	LS	IC	IC	USER	LS
IV	LS	USER	USER	USER	LS
V	USER	USER	USER	USER	USER

*SUPPORT MODULE, SUPPORT SYSTEMS, & EXPERIMENT MODULE STRUCTURE

Pallet-Only Processing Concepts

CONCEPT	OWNER		INTEGRATION SITE	
	PALLET	IGLOO*	EXPERIMENT EQUIPMENT	SPACELAB
VI	IC	LS	USER	LS
VII	IC	LS	IC	LS
VIII	USER	LS	USER	LS

*SUPPORT SYSTEMS IGLOO AND EQUIPMENT

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VIII

ABBREVIATIONS AND ACRONYM LIST

AAFE	Advanced Application Flight Experiments
ADDAS	Automated Digital Data Acquisition System
AEDC	Atomic Energy Development Center
AIM	Apogee Insertion Motor
AM	Airlock Module (Skylab)
ARINC	Aeronautical Radio, Inc.
ARS	Atmospheric Revitalization System
ASO	Airborne Science Office
ATCS	Active Thermal Control Subsystem
ATL	Advanced Technology Laboratory
ATM	Apollo Telescope Mount (Skylab)
CCTV	Closed Circuit Television
CDMS	Command and Data Management System
CER	Cost Estimating Relationship
C.G.	Center of Gravity
CKTS	Circuits
CM	Command Module (Apollo)
CPSE	Common Payload Support Equipment
CRT	Cathode Ray Tube
CSM	Command and Service Module (Apollo)
CV-990	Convair airplane used as test bed in airborne research by NASA-Ames Research Laboratory
DOMSAT	Domestic Satellite (commercial geosynch communications relay)
DPC	Data Processing Center
DWGS	Drawings
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control System
EDS	Experiment Discipline Specialist
EGSE	Electronic Ground Support Equipment
E/I	End Item (hardware)
EM	Experiment Module
EMC	Electromagnetic Compatibility
EMI/RFI	Electromagnetic Interference/Radio Frequency Interference
EPDS	Electrical Power and Distribution System
ERNO	European consortium developing Spacelab
ESRO	European Space Research Organization

FMEA	Failure Mode Effects Analysis
FO	Flight Operations
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
IC	Integration Center (sometimes inferred to be MSFC)
ICD	Interface Control Drawing
I/F	Interface
IMS	Information Management System
INSP	Inspection
IPS	Instrument Pointing System
IU	Instrument Unit (Saturn V Program)
JCL	Job Control Language
JSC	Lyndon B. Johnson Space Center
KSC	John F. Kennedy Space Center
LL	Lower Limit
LS	Launch Site
MCC	Mission Control Center (at JSC)
MCP	Monitor and Control Panel
MDA	Multiple Docking Adapter (Skylab)
MGT	Management
MIL-SPEC	Military Standard Specification
MSFC	Marshall Space Flight Center
MSOB (O&C)	Manned Spacecraft Operations Bldg (now Operations & Checkout)
MSS	Modular Space Station
MP	Mission Planning
NASCOM	NASA Communications Network
NCR	Non-Conformance Report
OBCO	On-Board Checkout
OCC	Operations Control Center (at Spacelab user's site)
O&C	Operations & Checkout Building (formerly MSOB)
OCP	Operational Checkout Procedure
OIT	Orbiter Integrated Test
OMS	Orbital Maneuvering System (Shuttle)
OWS	Orbital Workshop (converted S-IVB structure--Skylab)
OPF	Orbiter Processing Facility
P	Pallet or Pallet Section
PI	Principal Investigator
PS	Payload Shroud (Skylab)
PSS	Payload Specialist Station
QC	Quality Control
R	Rack or Rack Sets
RAU	Remote Acquisition Unit
R/I	Receiving/Inspection
R&QA	Reliability and Quality Assurance

SC 105	Spacecraft 105 (Apollo)
SCM	System Cost Model
SE	Systems Engineering
SIM	Scientific Instrument Model
SL	Spacelab
SM	Support Module
SPECS	Specifications
SSP	Space Shuttle Program
STDN	Space Tracking and Data Network
STS	Space Transportation System
SUIAS	Spacelab User Implementation Assessment Study
TCR	Test and Checkout Requirements
TDRS	Tracking and Data Relay Satellite
T&O	Test and Operations
U	User (inferred to be Langley)
UL	Upper Limit
WBS	Work Breakdown Structure
WTR	Western Test Range

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CONTENTS

ILLUSTRATIONS

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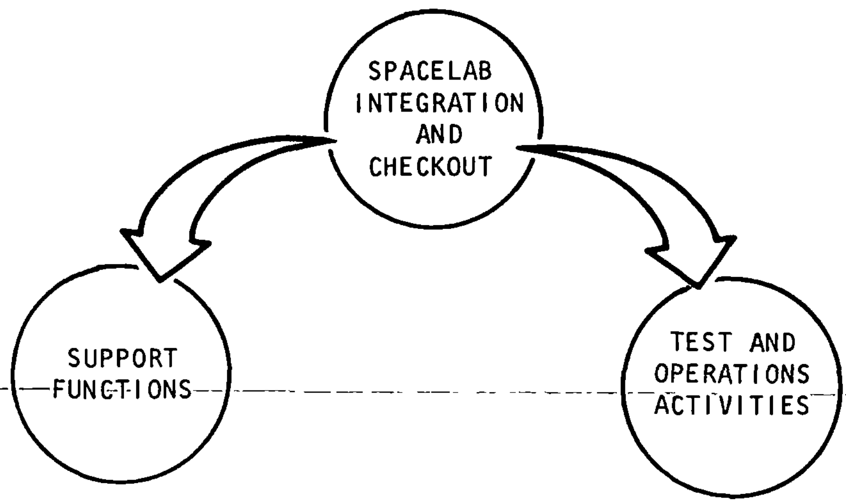
TABLES

1.0 INTRODUCTION

Volume II, Concept Optimizations, defines the integration and checkout activities associated with the ground operations for each Spacelab flight and establishes the preferred/optimal approaches to accomplish these activities. Integration and checkout activities are divided into two parts, as illustrated in Figure 1.0-1. The tasks associated with each part of the integration and checkout activities are indicated in the figure.



- Operations Analysis
- Requirements Definition
- System Design
- Interface Hardware Fabrication

- Experiment Installation
- Spacelab Test and Checkout
- Handling/Transportation Activities

Figure 1.0-1. Spacelab Integration and Checkout Elements

The support functions are defined for three types of activities: (1) mission-unique, (2) sustaining, and (3) non-recurring. The definition of the support functions is accomplished by the establishment of a WBS for each of the three types of activities. Each WBS contains only these tasks that relate to that particular type of activity. However, the WBS's are structured to facilitate the development of a composite WBS for all Spacelab integration and checkout activities.

The approach for the optimization of each type of support functions is also presented. The mission-unique support function optimization includes an evaluation of the roles and responsibilities of the PI's and the payload integrators. The sustaining support functions are definitized by deriving a management organization at each center that is tailored/optimized to the requirements of each processing concept. Use of the nucleus of a systems engineering organization is indicated for the accomplishment of non-recurring support functions. Where applicable, the use of software to expedite the accomplishment of all support functions is indicated. In addition, flight software requirements are defined and a test and validation technique is established.

Center support functions, which are concept-dependent, are defined by the use of derived responsibility criteria. These criteria are applied to key support function and hardware interfaces to identify primary, secondary, and supporting roles of the centers involved.

The definition of test and operations activities includes a preferred checkout approach. The approach reflects the objective of minimizing both recurring and non-recurring costs of the NASA for integration and checkout of Spacelab payloads. Checkout guidelines are established that reflect a test philosophy that stresses the verification of planned flight operations. Verification of functional operations rather than performance capabilities of the equipment is the objective of tests and operations activities.

The feasibility of utilizing the Spacelab data management system (DMS) in the preferred checkout approach is evaluated. Both operating and memory capacities of the DMS are analyzed.

The use of an SM simulator during Level III integration is compared with the use of the flight hardware to support checkout operations. This trade assesses the impact of including an SM simulator in the checkout sequence on total serial processing times of the flight hardware, and the required complement of flight hardware to support the anticipated Spacelab traffic model.

Checkout requirements are evaluated in three areas: functional, environmental, and operational. The functional requirements are analyzed for both the Spacelab/Orbiter and the experiment systems. The analysis of environmental checkout requirements involves the evaluation of six significant past space programs, the determination of trends in these past programs, and the applicability of the trends to an operational Spacelab program. Proposed Spacelab payload environmental verification techniques are defined. The operational checkout requirements include an analysis of the impact of payload cleanliness constraints and proposed shipping/transportation techniques on the sequence of installations and test/retest activities.

In the final part of the test and operations analysis, the test flow development is presented. The establishment of scenarios describing all of the test and operations activities relating to both the complete Spacelab and the pallet-only configurations are described. Expansion from functional block diagrams to at least two lower levels of detail is discussed. Integrated flight hardware processing timelines that reflect a summation of the expanded

test and operations details are presented. The serial flight hardware processing times for all eight concepts are summarized and compared.

The final section of this volume summarizes the involvement of the payload integrator in experiment systems development activities.

2.0 SUMMARY

The integration and checkout activities consist of two major sets of tasks: (1) support functions, and (2) test and operations. The support functions are definitized and the optimized approach for the accomplishment of these functions are delineated in Section 3.0 of this volume. Comparable data are presented for test and operations activities in Section 4.0 of this volume.

The support functions were divided into three types of activities:

1. *MISSION UNIQUE* - Must be accomplished for each flight.
   - Repeatable and can be considered directly attributable to the ground operations associated with an individual payload.

2. *SUSTAINING* - Encompasses the administrative, management, and institutional base support functions.
   - Independent of flight rates and/or individual Spacelab payload.

3. *NON-RECURRING* - Activities that adapt an operational Spacelab/Orbiter to the specific require- ments of a user.

The Spacelab payload integration and checkout WBS that was presented in Volume I was subdivided to illustrate which elements or tasks are mission-unique, sustaining, or non-recurring support functions. The tasks that were applicable to each type of support function are shown in Figures 2.0-1, 2.0-2, and 2.0-3.

The optimization of the support function tasks is defined in detail in Section 3.2. This optimization was accomplished by establishing a preferred approach for each of the three types of activities. The approach for the accomplishment of mission-unique tasks was developed by first identifying the roles and responsibilities of the PI's and the payload integrator, and then synthesizing techniques to fulfill those responsibilities. Sustaining support functions were optimized by deriving a management/administrative organization that was tailored for each center's role in each processing concept. It was recommended that non-recurring support functions be accomplished by the nucleus of the mission-unique systems engineering organization.

The role of the PI in mission-unique support functions not only included the design, development, and performance verification of individual experiments but also the preparation of a data package for each experiment. This data package will include measurement and command lists, display nomenclature, support system requirements, trajectory constraints, operational procedures,

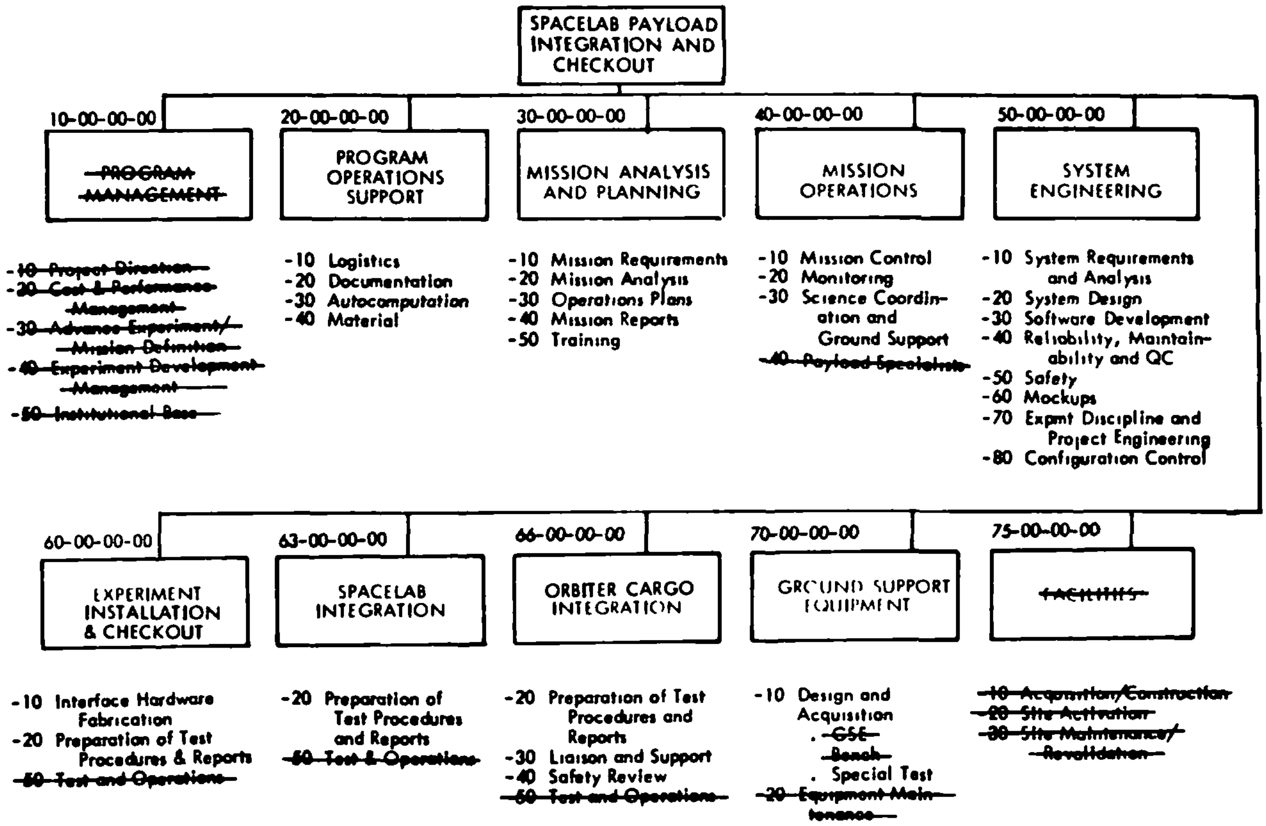


Figure 2.0-1. Mission-Unique Support Function WBS

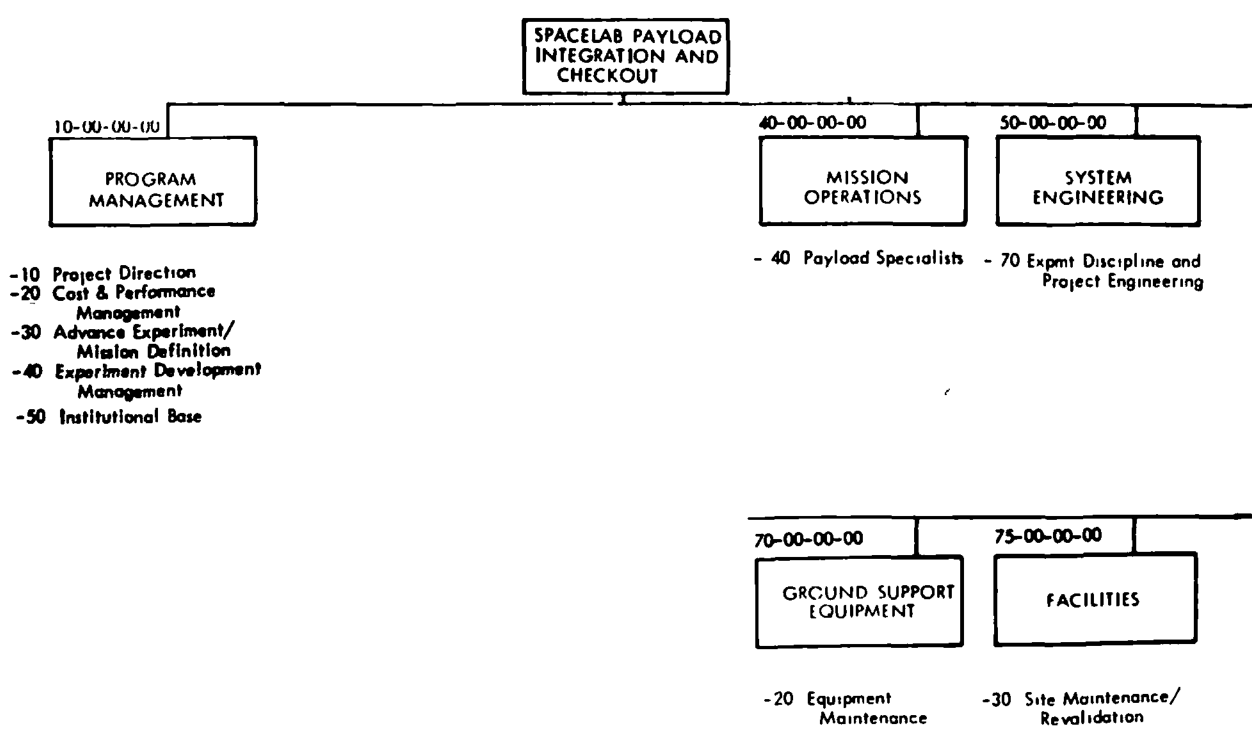


Figure 2.0-2. Sustaining Support Function WBS

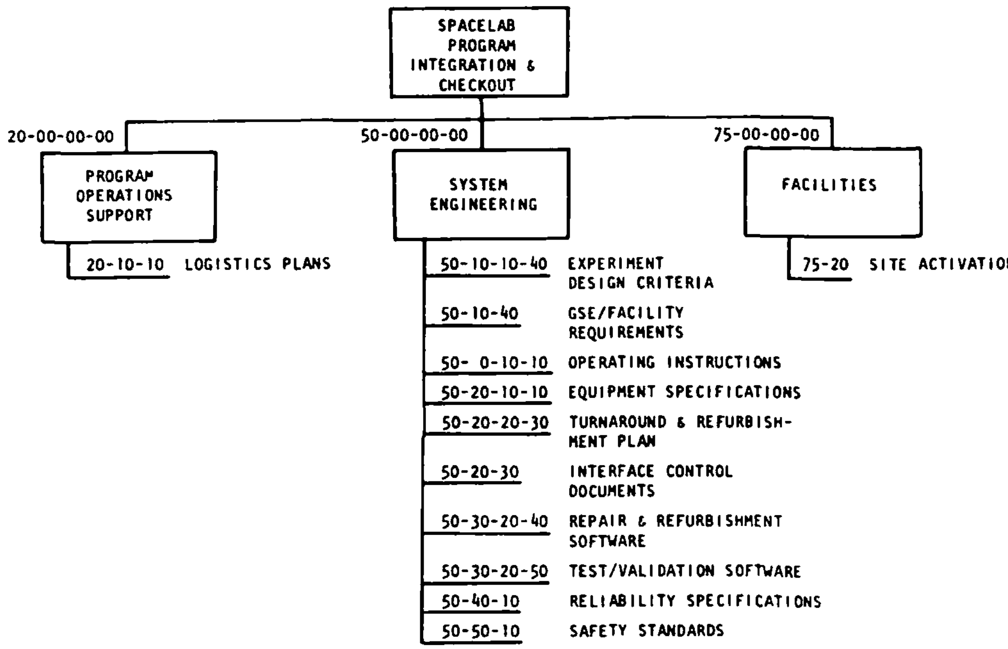


Figure 2.0-3. Non-Recurring Support Function WBS

ground truth site requirements, data processing/storage requirements, and a hazard analysis of the equipment and procedures. Identification of payload specialist skill requirements and the training of the payload specialists in the operation of the experiments were also the responsibility of the PI's.

Based upon the baseline data package prepared by the PI's, the responsibility of the payload integrators was to integrate/combine individual experiment system requirements into a compatible payload. This integration encompasses mission analysis and planning, mission operations, and systems engineering tasks. Mission analysis and planning activities include development of mission and payload specialist timelines. Computer-aided techniques such as Langley's Manned Activity Scheduling System (MASS) were recommended to expedite the process and reduce costs. Mission operations included real-time mission support at the user's site, Spacelab and Orbiter operator centers, and ground truth sites. A facility at the user's site for real-time data evaluation was recommended. Computer-aided analyses and design was also recommended for the accomplishment of systems engineering tasks. Standardized Spacelab/Orbiter accommodations will permit computerization of wire routing, panel layouts, space allocations, power and thermal profiles, etc.

In order to determine the roles of the individual centers in the accomplishment of the payload integration tasks, responsibility criteria were established (Table 2.0-1). The two principal themes of the criteria were (1) maintenance of owner cognizance throughout the integration process, and (2) configuration control of equipments and, most importantly, interfaces between assembly levels. The results of the application of these criteria to key integration and checkout interfaces are presented in Tables 2.0-2 and 2.0-3 for each of the processing concepts. Primary, secondary, and supporting roles of the involved centers are indicated.

Table 2.0-1. Responsibility Criteria

DRIVER	OWNERSHIP	CONFIGURATION MANAGEMENT
CRITERIA	MINIMUM PI/USER INVOLVEMENT	INTERFACE CONFIGURATION CONTROL BY OWNER OF NEXT LEVEL OF ASSEMBLY
	INSTALLATION SITE PROVIDES WORKING CREW; USER PROVIDES PAYLOAD SPECIALISTS	STRUCTURE FOR CONTINUING ATL PAYLOADS
	FLIGHT OPERATIONS SOFTWARE PREPARED BY EXPERIMENT INTEGRATOR	MODULE OWNER PROVIDES HARDWARE MODIFICATIONS
	GROUND TRUTH SITES OPERATED BY EXPMT INTEGRATOR AND PI	CPSE CONTROL AND INVENTORY BY OWNER OF NEXT LEVEL OF ASSEMBLY

Table 2.0-2. Key Experiment Integration Support Function Interfaces

	MISSION PLAN	OPER INSTR	PI/CREW TRAINING	GROUND SUPPORT	SYSTEM ANALYSIS	SYSTEM DESIGN	ORBITER SOFTWARE REQMTS
CONCEPT I	IC/LS	IC/U	U/IC	IC/U	IC	IC	IC/LS
CONCEPT II	IC/LS	IC/LS/U	U/IC/LS	IC/LS/U	IC	IC	IC/LS
CONCEPT III	U/LS	U/LS/IC	U/LS/IC	U/LS	U	IC	U/LS
CONCEPT IV	U/LS	U/LS	U/LS	U/LS	U	U	U/LS
CONCEPT V	U/LS	U	U	U	U	U	U/LS

NOTE: -/-/- = PRIMARY/SECONDARY/SUPPORTING

Table 2.0-3. Key Experiment Integration Hardware Interfaces

	EM/P MODS	SM MODS	CPSE	EXPERIMENT INSTALL	SPACELAB INTEG	CARGO INTEG	SL-OPNL SOFTWARE
CONCEPT I	IC	(IC)	IC/LS	IC/U	IC/U	LS/IC/U	IC/U
CONCEPT II	IC	(LS)	IC/LS	IC/U	LS/IC/U	LS/IC/U	IC/U
CONCEPT III	IC	(LS)	IC/LS	U/IC	LS/U	LS/U	U
CONCEPT IV	U	(LS)	U/LS	U	LS/U	LS/U	U
CONCEPT V	U	(U)	U/LS	U	U	LS/U	U

-/-/ = PRIMARY/SECONDARY/SUPPORTING
(-)= LITTLE IF ANY MODS OTHER THAN CPSE

In addition to the systems engineering tasks associated with the integration of procedures and flight hardware, flight and ground operations software was also required. Eight potential mission-unique software packages were identified. The packages were:

1.0 Flight Operations	5.0 Orbiter Support
2.0 Checkout/Performance Monitoring	6.0 Repair/Refurbishment
3.0 Fault Isolation/Diagnostic	7.0 Data Reduction
4.0 Test and Validation	8.0 Data Analysis

Fault Isolation/Diagnostic (Item 3.0) and Repair/Refurbishment (Item 6.0) were not recommended for experiment systems because of the flight-to-flight changes in experiment equipments. These two software items were recommended for Spacelab support systems. All other software packages were considered to be essential for the efficient accomplishment of support function tasks. Based upon extensive software studies conducted by JSC, KSC and MSFC, guidelines were formulated for the preparation of mission-unique software. The principal theme of the guidelines was to utilize machines and computer language that are readily understandable and usable by a broad spectrum of technical personnel. Computer expertise should not be a pre-requisite for Spacelab/payload software development.

The recommended approach for the test and validation of mission-unique Spacelab software is shown in Figure 2.0-4. In this approach, the PI can either provide a software module or a data package to the payload integrator. If the PI prepares only a data package, the payload integrator assembles a first-cut tape wherein the operations of the experiment and associated support systems are merged into one operating routine.

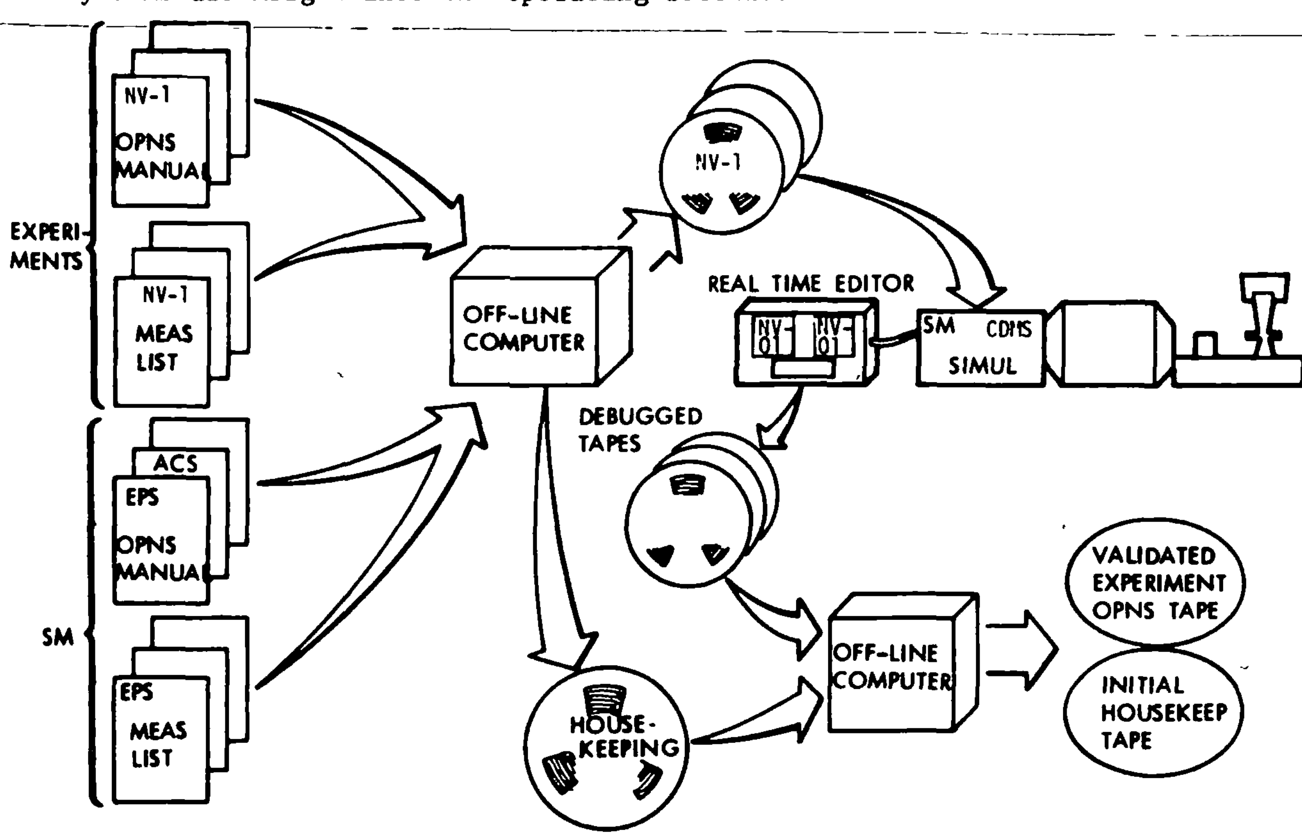


Figure 2.0-4. Level III Integration Modular Software Development

This routine (applications and data modules) is loaded into a simulator of the Spacelab Control and Data Management System (CDMS) along with the executive and operating system software, concurrent with the installation of that set of experiment equipment. If the PI elects to develop his own software, he delivers the software module with the experiment hardware as an additional end item of flight hardware.

In this approach, the *debugging* of the operating routine is accomplished during experiment installation and test; editing and modification (only the data module) is done on site by means of a real-time editor which is part of the test complex, but not part of the CDMS. Validated data modules for individual experiments are then assembled (off-line) into a mission tape. A similar process would prepare the Spacelab *housekeeping* tape at the next level of assembly.

This approach for the test and validation of Spacelab payload software minimizes the transfer of software requirements and responsibilities, and also reduces the required number of validations. All six applicable Spacelab payload software packages can be tested and validated with this approach.

The optimized test and operations checkout approach was established by utilizing the checkout guidelines illustrated in Figure 2.0-5.

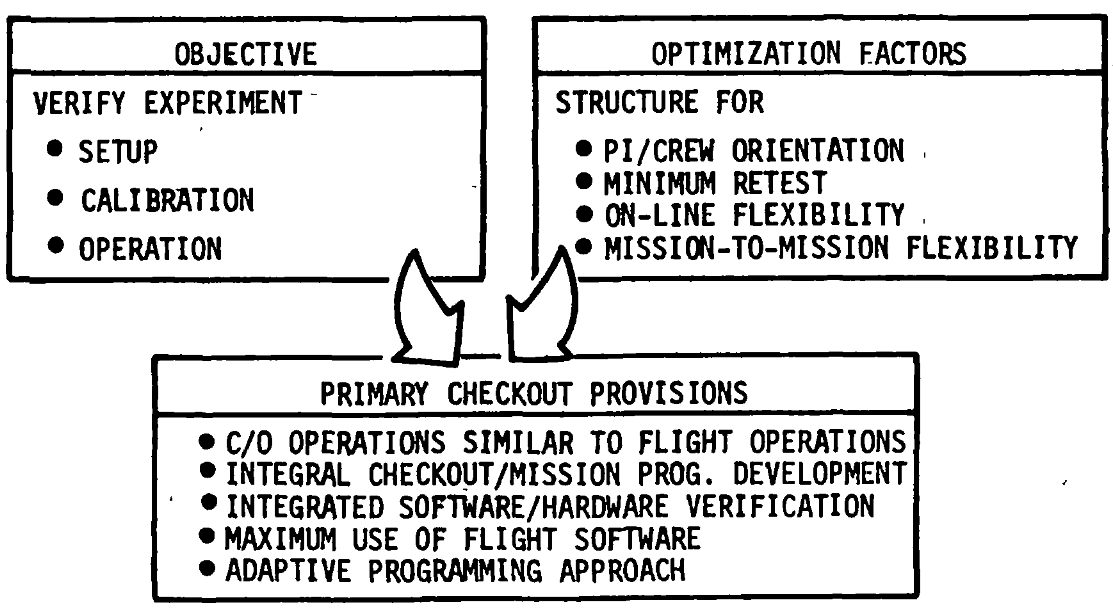


Figure 2.0-5. Checkout Guidelines

These guidelines reflect a test philosophy that stresses the verification of planned flight operations by limiting testing to the verification of on-orbit operations. Functional verifications, not performance or capability evaluations, were to be conducted during flight hardware processing.

As illustrated in Figure 2.0-6, three approaches to achieve the checkout guidelines were evaluated.

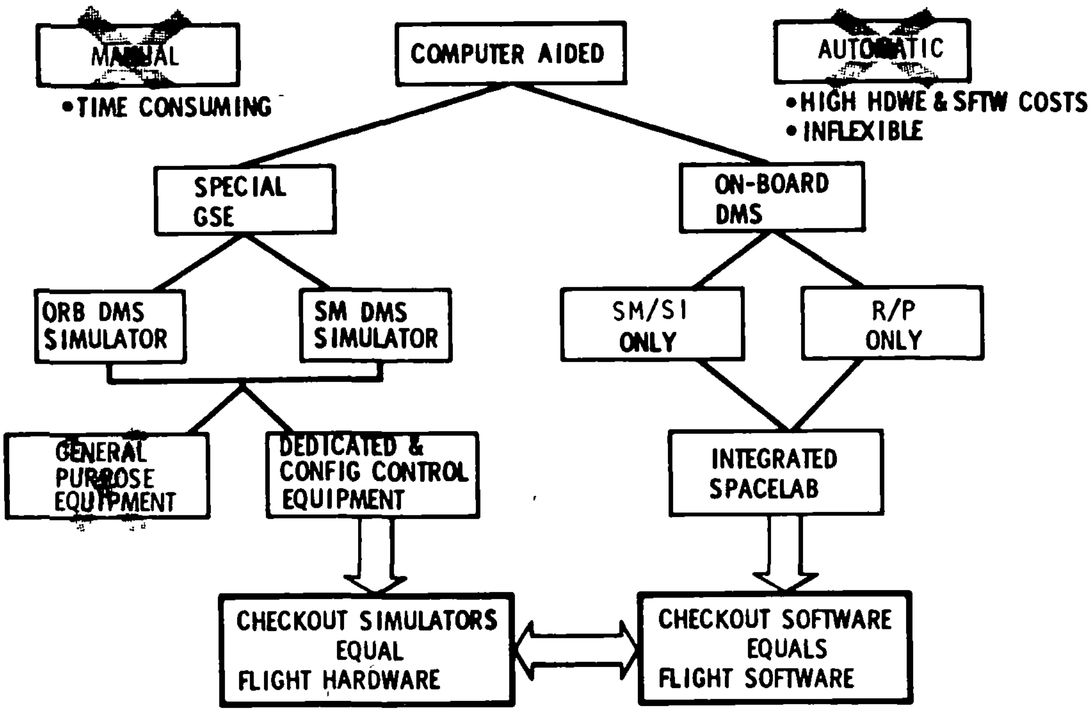


Figure 2.0-6. Alternate Checkout Implications

Analysis indicated that the computer-aided approach can be structured to meet all of the checkout guidelines. A feasibility analysis of the capability of the Spacelab Data Management System (DMS) to support Level III integration was conducted. Estimates of the ground and on-orbit data processing requirements for both Spacelab support systems and experiment systems were developed. The compatibility evaluation indicated that the DMS can accommodate both systems, provided additional mass memory (tape recorders) are provided.

Use of an SM simulator during Level III integration was compared to the use of the flight SM. Total serial processing time of the flight hardware and the complement of flight hardware required to support the anticipated Spacelab traffic model were evaluated. In general, simulator utilization did not affect the serial processing time of the payload but did significantly decrease the required complement of flight SM's at higher flight rates. Use of a support systems simulator during Level III integration was adopted for all processing concepts.

Three categories of checkout requirements were evaluated: functional, environmental, and operational. Within the area of functional checkout requirements, two major test activities were considered: Spacelab/Orbiter, and experiments. In this study, the Spacelab/Orbiter were considered ongoing operational programs. Test activities involving these two program

elements were limited to functional reverification as required and interface verification. Complete functional verification of experiment systems and interfaces was required. Use of planned on-orbit operations during testing was to be maximized.

The various environments that experiment equipment will be exposed to during payload processing and orbital missions were analyzed, and a preferred environmental verification approach was defined. Based upon the operational nature of the Spacelab/Orbiter, analytical techniques for environmental compatibility evaluations of the integrated payload were selected. Only electromagnetic compatibility verification required empirical testing at the integrated payload level of assembly. Environmental testing of individual experiment equipments will be required.

The recommended mode for the transport/shipping of assembled Spacelab elements was to utilize the 747 piggyback mode. If only racks and pallets were involved, and the combined pallet-sensor height was less than 11.5 feet, then the C-5A aircraft was the preferred shipping approach. Retesting after major moves was limited to receiving-inspection type activities.

Test and operations sequences were derived from hardware processing scenarios for each concept. Major functional activities were defined and expanded at least two additional levels of detail. Time allocations were established for each expanded activity, and then summarized to an integrated/contiguous sequence of tests and operations. Table 2.0-4 summarizes the serial processing times for the complete Spacelab concepts. A summation of the serial processing times for the pallet-only concepts is presented in Table 2.0-5. The differences in processing times between concepts for comparable Spacelab configurations were due to shipping/handling variations.

Table 2.0-4. Summary of T&O Times for the Complete Spacelab Processing Concepts

BLOCK	MAJOR FUNCTIONAL ACTIVITY	BLOCK TIME (DAYS)	OVERLAP TIME	PARALLEL TIMES	SERIAL PROCESSING TIMES I	II	III	IV	V
1.0	EXPERIMENT SHIPMENT	6.0		X					
2.0	EXPERIMENT INSTALLATION	22.0			22.0	22.0	22.0	22.0	22.0
3.0	CONNECT SM INTERFACE SIMULATOR	5.7	2.5		3.2	3.2	3.2	3.2	3.2
4.0	EXPERIMENT INTEGRATION	36.0			36.0	36.0	36.0	36.0	36.0
5.0	GSE DISCONNECT	0.9		X					
6.0	RACKS/PALLET SHIPMENT	6.7				6.7	6.7	6.7	
7.0	MATE RACKS/PALLET - EM/SM SHELLS	3.0			3.0	3.0	3.0	3.0	3.0
8.0	SPACELAB INTEGRATION	10.4			10.4	10.4	10.4	10.4	10.4
9.0	SPACELAB SHIPMENT TO LAUNCH SITE	3.6			3.6				3.6
10.0	SPACELAB OFFLOAD	2.7			2.7				2.7
11.0	ORBITER CARGO INTEGRATION	4.7	0.2		*4.5	4.7	4.7	4.7	*4.5
12.0	LAUNCH OPERATIONS	4.2			4.2	4.2	4.2	4.2	4.2
13.0	MISSION OPERATIONS (REF)	5.0			5.0	5.0	5.0	5.0	5.0
14.0	POSTFLIGHT OPERATIONS	1.9			1.9	1.9	1.9	1.9	1.9
15.0	SPACELAB MOVE TO MSOB	2.6				2.6	2.6	2.6	
16.0	SPACELAB SHIPMENT FROM LAUNCH SITE	5.4			5.4				5.4
17.0	DEMATE EM/SM SHELLS	1.2			1.2	1.2	1.2	1.2	1.2
18.0	RACKS/PALLET SHIPMENT	6.7				6.7	6.7	6.7	
19.0	REFURBISH RACKS/PALLET	8.2			8.2	8.2	8.2	8.2	8.2
20.0	EXPERIMENT SHIPMENT	5.5		X	-				
21.0	REFURBISH SUPPORT SYS & EM/SM SHELLS	8.2	8.2	X					
22.0	POST-REFURBISH RACKS/PALLET SHIPMENT	6.5					6.5		
		TOTAL (WORKING DAYS)			111.3	115.8	122.3	115.8	111.3

*CONCEPTS I AND V ONLY

Table 2.0-5. Summary of T&O Times for Pallet-Only Processing Concepts

BLOCK	MAJOR FUNCTIONAL ACTIVITY	BLOCK TIME (DAYS)	OVERLAP TIMES	PARALLEL TIME	SERIAL PROCESSING TIME CONCEPT VI	VII	VIII
1.0	EXPERIMENT SHIPMENT	7.0/1.0		X			
2.0	EXPMT INSTALL. (PALLET/IGLOO)	21.0			21.0	21.0	21.0
3.0	CONNECT & C/O IGL/ORBITER SIM SET	5.7	3.7		2.0	2.0	2.0
4.0	EXPERIMENT C/O & INTEGRATION	36.0			36.0	36.0	36.0
5.0	GSE DISCONNECT	2.5		X			
6.0	PALLET/IGLOO SHIPMENT	3.5			3.5	3.5	3.5
7.0	P/IGL & PSS EQUIP ARRIVAL & R/I	2.4			2.4	2.4	2.4
8.0	MATE PALLET & IGLOO (SUPPORT SYST)	2.7			2.7	2.7	2.7
9.0	SPACELAB INTEGRATION	10.2			10.2	10.2	10.2
10.0	ORBITER CARGO INTEGRATION	4.2			4.2	4.2	4.2
11.0	LAUNCH OPERATIONS	4.2			4.2	4.2	4.2
12.0	MISSION OPERATIONS (REF)	5.0			5.0	5.0	5.0
13.0	POSTFLIGHT OPERATIONS	1.9			1.9	1.9	1.9
14.0	REFURBISH SUPPORT SYSTEMS IGLOO	7.5		X			
15.0	PALLET/IGLOO SHIPMENT	5.0			5.0	5.0	5.0
16.0	REMOVE EXPMTS/EQUIP FROM P/IGLOO	5.0			5.0	5.0	5.0
17.0	EXPERIMENT SHIPMENT	2.5		X			
18.0	REFURB/RECONFIG PALLET & IGLOOS	3.0			3.0	3.0	3.0
19.0	POST-REFURB P/IGLOO SHIPMENT	5.6			5.6		
		TOTALS			111.7	106.1	106.1

3.0 SUPPORT FUNCTIONS

Integration and checkout activities associated with the ground operations for each flight consist of two major sets of tasks: (1) support functions, and (2) test and operations. The first set of tasks pertains to the operations analysis, requirements definition, system design, and interface hardware fabrication activities. The second set of tasks pertains to the installation, test, handling, and transportation activities associated with the actual processing of the flight hardware, and the associated GSE and special test equipment.

In this section, the support functions are definitized and the optimization approach for the accomplishment of these functions is delineated. Test and operations activities are definitized in a subsequent section of this report.

The complete Spacelab integration and checkout WBS, developed in Volume I, is used to graphically illustrate which elements of that WBS are support functions. The optimization of the conducting of the support functions tasks is presented in the second part of this section. Use of software is emphasized. Responsibility criteria are established that maximize PI/user involvement throughout ground operations, and minimize responsibility transfers and corresponding documentation requirements.

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3.1 DEFINITION OF SUPPORT FUNCTIONS

In order to facilitate the definition of support function resource requirements, the functions were defined in three classes of activity: (1) mission-unique, (2) sustaining, and (3) non-recurring. The first class pertains to those activities that must be accomplished for each and every mission; they are repeatable and can be considered directly attributable to the ground operations associated with an individual Spacelab payload. Sustaining activities encompass administrative, management, and institutional base support functions that are relatively independent of flight rate and/or individual Spacelab payloads. Non-recurring support functions pertain to those activities that adapt an operational Spacelab/Shuttle to the specific requirements of a user. Each class of support functions is defined in this section.

MISSION-UNIQUE SUPPORT FUNCTIONS

Figure 3.1-1 presents the composite work breakdown structure (WBS), developed in Volume I, for integration and checkout of a Spacelab payload. Those activities that are not mission-unique support functions have been lined out. Since detailed descriptions for each WBS entry are presented in Volume I, only a summary of the mission-unique support functions are presented here.

Program Operation Support (20-00-00-00)

The support services included in this WBS group include all non-personnel cost items. Travel and per-diem expenses for engineering liaison and mission support, as well as packaging and shipping charges associated with the transfer of flight hardware between processing centers, are included as part of Logistics (20-10-00-00). The effort and materials associated with editing and production of required documentation are included in the 20-20-00-00 entry. Engineering effort to develop the technical content of the documentation is not included in 20-20-00-00. Only machine (computer) run time is included in the Autocomputation entry (20-30-00-00). Procurement of material for interfacing hardware is included in 20-40-00-00. Neither the design nor the fabrication of the hardware is included. Also, the procurement of Spacelab and experiment equipment are excluded from 20-40-00-00, as this WBS is applicable only to integration and checkout; it is not a programmatic WBS. The technical effort associated with these support services is included in the other mission-unique WBS task groups discussed in subsequent paragraphs.

Mission Analysis and Planning (30-00-00-00)

The tasks of this WBS group pertain to the engineering effort to investigate, analyze, and correlate various mission factors to achieve a mission plan that is compatible with experiment objectives and Spacelab/Shuttle capabilities. The factors to be considered include alternate flight trajectories, ground truth site requirements, expendable resources, and Shuttle and payload

SPACELAB PAYLOAD INTEGRATION AND CHECKOUT

- 10-00-00-00 ~~PROGRAM MANAGEMENT~~
  - ~~-10 Project Direction~~
  - ~~-20 Cost & Performance Management~~
  - ~~-30 Advance Experiment/Mission Definition~~
  - ~~-40 Experiment Development Management~~
  - ~~-50 Institutional Base~~
- 20-00-00-00 PROGRAM OPERATIONS SUPPORT
  - -10 Logistics
  - -20 Documentation
  - -30 Autocomputation
  - -40 Material
- 30-00-00-00 MISSION ANALYSIS AND PLANNING
  - -10 Mission Requirements
  - -20 Mission Analysis
  - -30 Operations Plans
  - -40 Mission Reports
  - -50 Training
- 40-00-00-00 MISSION OPERATIONS
  - -10 Mission Control
  - -20 Monitoring
  - -30 Science Coordination and Ground Support
  - ~~-40 Payload Specialists~~
- 50-00-00-00 SYSTEM ENGINEERING
  - -10 System Requirements and Analysis
  - -20 System Design
  - -30 Software Development
  - -40 Reliability, Maintainability and QC
  - -50 Safety
  - -60 Mockups
  - -70 Expmt Discipline and Project Engineering
  - -80 Configuration Control
- 60-00-00-00 EXPERIMENT INSTALLATION & CHECKOUT
  - -10 Interface Hardware Fabrication
  - -20 Preparation of Test Procedures & Reports
  - ~~-50 Test and Operations~~
- 63-00-00-00 SPACELAB INTEGRATION
  - -20 Preparation of Test Procedures and Reports
  - ~~-50 Test & Operations~~
- 66-00-00-00 ORBITER CARGO INTEGRATION
  - -20 Preparation of Test Procedures and Reports
  - -30 Liaison and Support
  - -40 Safety Review
  - ~~-50 Test and Operations~~
- 70-00-00-00 GROUND SUPPORT EQUIPMENT
  - -10 Design and Acquisition
    - . ~~GSE~~
    - . ~~Bench~~
    - . Special Test
  - ~~-20 Equipment Maintenance~~
- 75-00-00-00 ~~FACILITIES~~
  - ~~-10 Acquisition/Construction~~
  - ~~-20 Site Activation~~
  - ~~-30 Site Maintenance/Revalidation~~

Figure 3.1-1. Mission-Unique Support Function WBS

specialist crew timelines. The basic products of the tasks in this WBS group are mission operational requirements and procedures, training plans, and (upon completion of this mission) analyses and reporting of mission accomplishments.

Mission Operations (40-00-00-00)

All the activities of the WBS group pertain to ground support of the flight. Real-time mission support at Shuttle, Spacelab, ground truth site, and user operations control centers is included.

System Engineering (50-00-00-00)

The tasks of this WBS group encompass the effort to convert mission and operations requirements into a system design. The effort includes both interface hardware design and software development/validation. Development of expendables, thermal, and power profiles that reflect planned experiment activities and operations are included. Where applicable, form-and-fit mockups and training aids are designed and fabricated within this group of tasks. Both reliability and safety evaluations are conducted in conjunction with the PI's. Combined experiments, Spacelab and Orbiter operations are considered in the system engineering effort. Determination and control of the center of gravity and weight of the integrated payload as well as the configuration management of all the involved flight hardware is also accomplished as part of this task group.

Experiment Installation and Checkout (60-00-00-00)

Mission-unique support functions in this task group are limited to the fabrication of interface hardware and preparation of Level III integration (checkout) procedures and reports. The actual assembly and test of experiment equipment, interface hardware, and Spacelab equipment is also included in this task group but is discussed as part of test and operations activities.

Spacelab Integration (63-00-00-00)

Since the interfaces at the Spacelab integration (checkout) level are to be standardized, only the preparation of test procedures and reports are considered to be mission-unique supporting functions in this WBS group.

Orbiter Cargo Integration (66-00-00-00)

In addition to the preparation of test procedures and reports, the coordination and reviews required to establish the flight readiness of the Shuttle/Spacelab/payload are also included as part of the support functions of this WBS group.

Ground Support Equipment (70-00-00-00)

It is anticipated that special GSE will be required for the installation and checkout of experiment equipment. In general, all unique electronic equipment is assumed to be furnished by the PI's; however, stands, supports, slings, etc., to position/hold the PI's electronic equipment (because of

the physical constraints imposed by the assembled equipment) will be required. The design and fabrication of this mission-unique handling equipment is the support function task in this WBS group.

SUSTAINING SUPPORT FUNCTIONS

The principal characteristic of all the sustaining support functions is that they are of a continuous nature. These activities are relatively independent of flight rate and pertain to the accomplishment of the entire program rather than a specific flight.

Only that portion of the integration and checkout WBS that is applicable to sustaining support functions is indicated in Figure 3.1-2. Program Management (10-00-00-00) is included in this support function class because the activities of this WBS group pertain to the administration (Cost and Performance Management) and management (Project Direction) of the integration and checkout of a Spacelab payload, or the operation of the NASA centers involved (Institutional Base).

Although the Advanced Experiment/Mission Definition (10-30-00-00) and Experiment Development Management (10-40-00-00) activities are not specifically part of integration and checkout, they were included in this WBS to emphasize the required interrelationship of the various facets of a continuing Spacelab payload program such as the ATL.

The Payload Specialists (40-40-00-00) are considered to be part of the sustaining effort. These members of the flight crew will probably be principal investigators or personnel specifically trained to operate experiments in space. Their activities will encompass more than just the integration and checkout facets of a Spacelab payload program. Thus, these personnel and their associated effort are considered to be a staff function.

Experiment Discipline and Project Engineering activities (50-70-00-00) are considered to be staff efforts. Discipline specialists will provide the interface between experiment development activities and integration and checkout activities. These activities will be a continuing effort that spans proposed, planned, and in-process payloads. Although project engineering can be identified with a specific mission, its primary function is to manage and direct the integration and checkout activities of all the line organizations.

Equipment Maintenance (70-20-00-00) and Site Maintenance/Revalidation (75-30-00-00) encompass the periodic servicing, repair, and calibration associated with the electrical and mechanical ground support equipment and facilities used in test and operations activities. General site maintenance (cleaning, painting, etc.) is not part of those two WBS items; it is included in the institutional base.

NON-RECURRING SUPPORT FUNCTIONS

The non-recurring support functions consist of those activities that are necessary to adapt an operational Shuttle/Spacelab to the specific requirements of a user. It is assumed that a basic data pack that provides ground rules

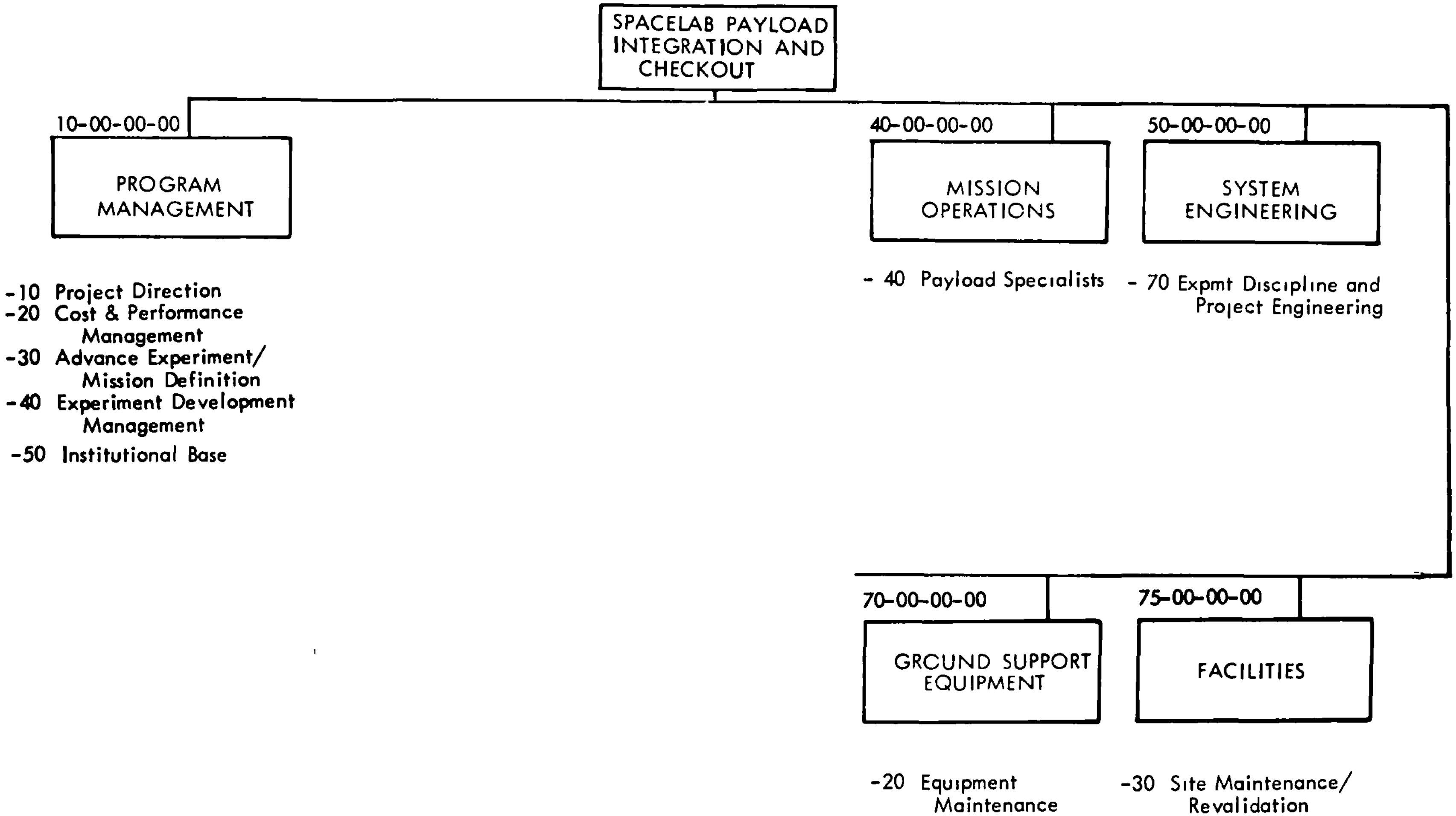

Figure 3.1-2. Sustaining Support Function WBS

and guidelines for the integration and checkout of payloads will be formulated as part of the development of an operational Shuttle/Spacelab system. But the broad spectrum of users will have diverse application requirements. For example, each user will be required to develop logistics plans, repair/refurbishment/inspection procedures, and GSE and facility requirements that are commensurate with the physical and procedural constraints of the user center and reflect the planned flight rate of the user.

Non-recurring support function tasks were intentionally grouped with mission-unique support function tasks to reflect the potential for continuity of effort. The non-recurring tasks are included in three WBS groups as indicated in Figure 3.1-3. All but two of the tasks are included within System Engineering.

The non-recurring tasks consist of four types of activities: (1) flight hardware processing, (2) design guidelines, (3) design characteristics, and (4) processing accommodation at the user's site. Each type of activity and the associated WBS tasks are defined in subsequent paragraphs.

Flight Hardware Processing

Logistic Plans (20-10-00-00) for the shipment of experiment equipment and Spacelab flight hardware must reflect geographical location of the user and the physical constraints and capabilities of a user's site. Intra-site handling, loading, and transporting of Spacelab equipment to/from the departure point (usually an airport) will be unique at each user's site.

Although maintenance schedules for Spacelab equipment are assumed to be established as part of the Spacelab development effort, flight rate and Spacelab configurations of each user will vary. Also, some experiment equipment will require special handling or may be utilized on successive flights. Thus, each user must develop a Turnaround and Refurbishment Plan (50-20-20-30) that is tailored to the planned usage of the flight hardware.

A corollary to this requirement is the development of Repair and Refurbishment Software (50-30-20-40) to analyze and evaluate equipment performance data. Trends in performance/capability must be established to define timely maintenance/repair/refurbishment action.

Design Guidelines

Basic Shuttle and Spacelab payload accommodations will be provided to the user and will include generalized guidelines for experiment equipment design. But the broad spectrum of disciplines and experiment equipment that will be included in Spacelab payloads precludes direct application of these guidelines by a Spacelab user. Each user will be required to develop Experiment Design Criteria (50-10-10-40) tailored to the objectives, mechanizations, and equipment of his program.

Reliability Plans and Specifications (50-40-10-00) could vary significantly between payloads. In some cases, on-board spares/repair may be practical; multiple flights with the same equipment may be planned; or technology limitations may restrict the equipment design.

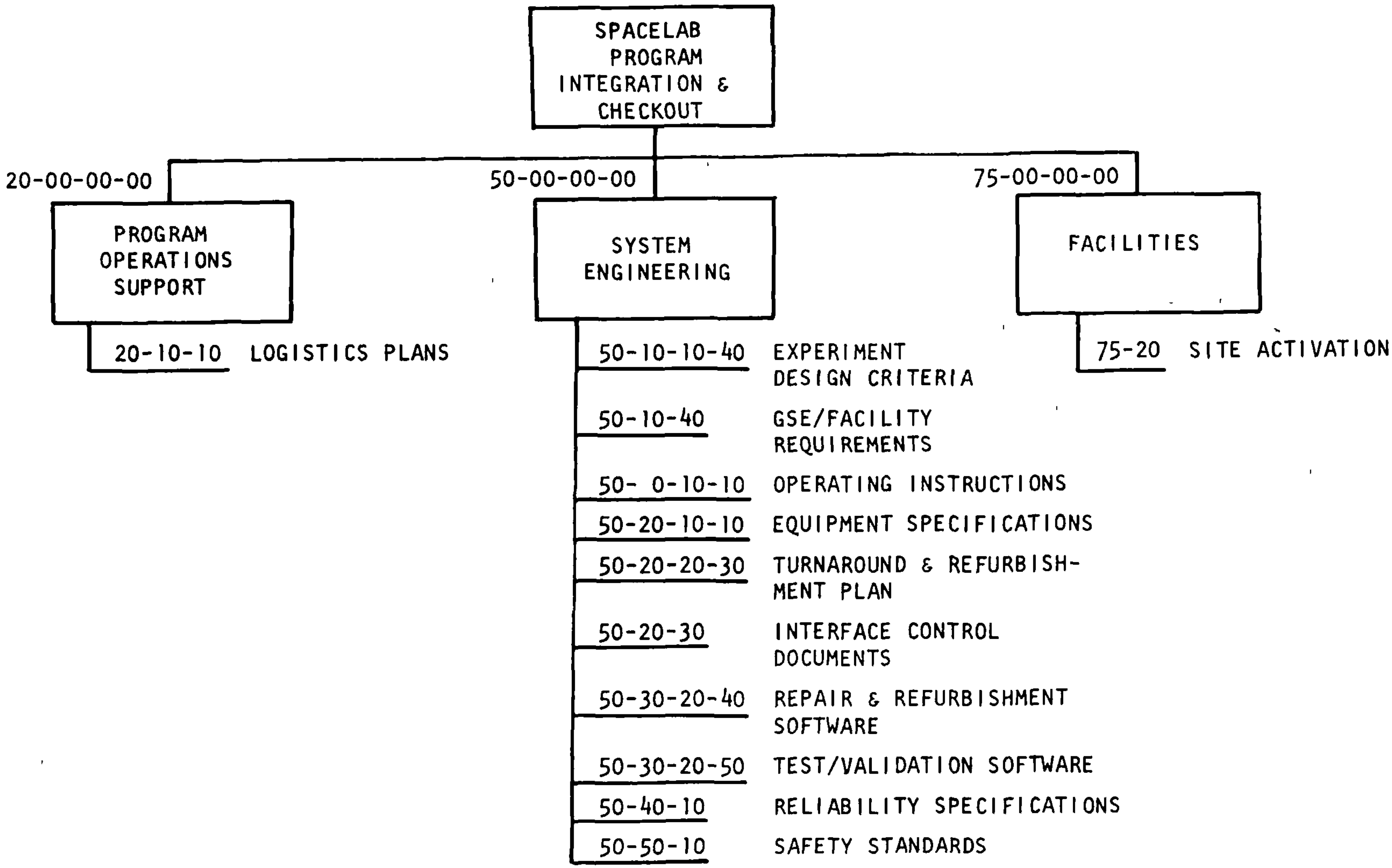

Figure 3.1-3. Non-Recurring Support Function WBS

It is recognized that stringent safety requirements will be imposed by both the Shuttle and the Spacelab to ensure both personnel safety and Shuttle/Spacelab integrity. But unique Safety Standards and Criteria (50-50-10-00) will be required from each user that reflect the peculiarities of his experiment equipment. Fluids, test specimens, and radiation sources that may be used in advanced technology experiments will require the establishment of unique safety controls to be used during both ground and flight operations.

Payload mechanization will vary between users and between Spacelab configurations. Some experiments will, by their very nature, require automated operation. Experiment equipment mounted on pallet sections must be remote-controlled. Wire harness limitations will impose the requirement to use the Spacelab data bus/remote acquisition unit capability. All of these characteristics imply the use of software for experiment operation. Although the software may be unique from flight to flight, Test and Validation Software (50-30-20-50) can be standardized to expedite the integration and checkout activities.

Design Characteristics

Operational compatibility between the payload, Spacelab, and Orbiter is just as essential as equipment compatibility. Each user program will have a set of objectives that reflects the user's expertise and field of research. Operating modes and equipment characteristics will correspond to each user's unique experiments. Thus, Operating Instructions (50-20-10-10) and Equipment Specifications (50-20-10-20) that are tailored to the individual user's program are required. These activities must convert the generalized instructions for operation of Orbiter and Spacelab equipment and, specifically, common payload/multi-mission support equipment, to the planned application with user experiments. Specifications must reflect the specific design interface between experiment equipment and Orbiter/Spacelab equipment to control the design and development of experiment hardware.

In addition to the controls on the operation and design of the experiment hardware, control of other interfaces with standardized Orbiter/Spacelab equipment is required. It is essential that both operational and hardware compatibility with these two higher levels of assembly is assured. Formal Interface Control Documents (50-20-30-00) are required to assure this compatibility for both ground and flight operations.

Processing Accommodations at the User's Site

General requirements for GSE and facilities for the Spacelab will be generated as part of the development of an operational Spacelab. But the existing accommodations at each user site will be unique. Also, user programmatic planning will vary. One user's plan may exhibit a slow rate of growth in the planned number of flights per year; another user may plan for a rapid growth rate or even discrete steps in flight rate. Thus, each user must develop GSE and Facility Requirements (50-10-40-00) that reflect existing capabilities and programmatic planning. Site Activation (75-20-00-00) plans must also correspond to the user's programmatic approach.

3.2 OPTIMIZATION OF SUPPORT FUNCTION TASKS

The approach developed in this study to accomplish the support function tasks is delineated in this section. The preferred approach to accomplish mission-unique tasks associated with mission analysis and planning, mission operations, and systems engineering is presented. The principal investigator's role and responsibilities in the accomplishment of these tasks are also identified. Where applicable, the use of software to accomplish these tasks is indicated. Responsibility criteria were developed to define the interrelationships between involved centers for each candidate processing concept.

Instead of attempting to develop a technique for the accomplishment of each sustaining support function, an organizational approach which would encompass all the tasks was selected. Center and organizational interrelationships are clearly defined by this approach.

Accomplishment of non-recurring support function tasks are dependent upon the Spacelab user's program plan. Funding and schedule constraints will be the primary drivers in the specific technique to accomplish the tasks. The recommendation is made to plan non-recurring support function tasks as the initial effort of a systems engineering organization.

APPROACH TO MISSION-UNIQUE SUPPORT FUNCTIONS

In order to establish a preferred approach for the accomplishment of mission-unique support functions to be performed by a user, IC, and/or LS, the role and responsibilities of the principal investigators (PI) must first be defined. A clear definition of what is expected of the PI's will then permit the definitization and optimization of mission analysis and planning operations, and systems engineering activities of the experiment or payload integrators.

Principal Investigator's Role and Responsibilities

Each experiment consists of a unique sensor(s) supplemented by support instrumentation including specific display, processing, and control equipment. These equipments and the associated procedures for use, handling, packaging, and installation in standard racks, support canisters, or on pallet segments are delivered to the experiment integrator. It is the responsibility of the PI to design, develop, and performance test the experiment equipment. Some of these PI activities are completed prior to the initiation of integration and checkout activities definitized in this study.

The PI's must provide a documentation data package for each experiment to enable the experiment integrator to perform the mission-unique support functions. This data package must include a hazards analysis, measurement and command list, display nomenclature, support requirements (power, cooling, data

storage, communications, etc.), mission profile requirements (viewing angles, ground targets, truth sites, trajectories, etc.), and payload specialist requirements (set-up, calibration, operation procedures and timelines). The experiment integrator will, in turn, combine the data package for all experiments of a Spacelab payload into a composite/integrated/compatible flight plan.

The PI must demonstrate the operability of his experiment equipment in a simulated flight configuration prior to actual installation in/on Spacelab equipment. To facilitate this demonstration the experiment integrator will provide to the PI the cabling, supports, mounts, adapters, and equivalent support provisions (power, cooling, data recording, etc.).

The selection of the payload specialist members of the flight crew is the joint responsibility of the PI's and the experiment integrator. Ideally, the PI's would be the payload specialists. In reality, this would be the exception for the following reasons.

1. The number of payload specialists that can be accommodated in the Orbiter is four; there are several disciplines involved (in the ATL), each with several experiments on any one flight.

2. Generally, the term "PI" is used collectively; several associated individuals, each interested in a different aspect of an experiment, are involved.

3. The PI is responsible for ground truth site activities during the mission as well as on-orbit activities. The PI must manage the entire operation--not just operate the equipment.

Note that a particular PI being a payload specialist is not precluded. But it is presumed that a cadre of discipline specialists that have also been trained in space-flight operations will be established as a support group that will provide the required payload specialists for each flight.

The cadre of payload specialists must receive training in the operation of the PI's equipment, and develop a rapport with the PI's in order to effectively and efficiently achieve experiment objectives. This training is also the responsibility of the PI's and will be accomplished at both the individual experiment level and the integrated payload level. The payload specialists for a given flight will work with the PI's in their laboratories during prototype hardware development and initial mission planning activities. The operators during individual experiment acceptance tests, installed experiment testing, combined experiment testing, and integrated Spacelab testing are the PI's and/or the payload specialists. In this manner, the PI's are directly involved throughout the processing of the flight hardware and the payload specialists are developing familiarization with the equipment, objectives, and procedures of the experiments as well as training with the actual flight hardware. This training approach also eliminates the need for complex and costly mission simulators.

It is believed that this approach to the roles and responsibilities of the PI's will facilitate the integration and checkout of Spacelab payloads; maintain the direct involvement and experiment responsibility of the PI's; ensure compatibility of flight hardware; and provide payload specialists who are acceptable to and trained by the PI's, in the least expensive and most effective manner to fulfill the requirements of a Spacelab payload program.

Payload Integrator Responsibilities

It is the responsibility of the payload integrator to perform the mission-unique support functions--i.e., to provide the liaison and coordination between PI mission objectives and flight hardware, and the accommodations and capabilities of the Spacelab and Orbiter. Although the center primarily responsible for payload integration varies between processing concepts analyzed in this study (i.e., user in Concepts IV, V, VIII; IC in I, II, and VII; and IC and user in III and VI), the basic support function tasks are the same regardless of concept. The preferred approach to these tasks (mission analysis and planning, mission operations, and systems engineering) is discussed herein. The interfaces between involved centers are discussed subsequently.

Mission Analysis and Planning

Mission analysis and planning requires the investigation of a large number of peripheral but interrelated factors pertaining to a flight plan to select an optimum combination that will maximize the useful results of a mission. Included in these factors are trajectory correlation to on-orbit and ground truth site activities, view angles, target resolutions, target lighting, payload specialists and composite flight crew scheduling, and attitude or pointing profiles. The analyses to correlate all of these factors are an iterative interaction process that is modified and refined to an eventual flight plan definition.

Traditionally, mission analysis and planning requires a great deal of unique expertise in a variety of skills, plus some one individual who can integrate and evaluate tradeoffs that have no quantifiable functional relationships. Thus, it would require a large number of highly specialized personnel for a relatively short time.

An alternative is to subcontract this effort to a NASA center that has had similar previous experience. This center might provide this service to many users concurrently. A significant disadvantage is that the Spacelab user would have minimal control over the tradeoffs, and a relatively long time delay would occur between iterations. Only the user can judge the tradeoff relationships and initiate meaningful alternatives. Therefore, he must become knowledgeable about all these factors. On this basis, the time delay between iterations becomes an intolerable constraint.

An option that could relax this constraint is possible. The mission analyst does not have to be an expert in orbital mechanics to obtain a trajectory plot. The algorithm and computation capability already exists as well-developed computer software. By entering initializing and boundary data, and calling for this (or other) program, a computer can print or plot the relevant information. Thus, a remote terminal at the user's location, tied to another center's computer, could provide a rapid turnaround. This option has two impacts: (1) whether the other center would make its computer available as a time-shared processing complex to all users, and (2) the cost of leasing landlines between this center and all users. There is then the question of how many different programs (ground truth site look-angles, aircraft paths, crew timeline scheduling) could be available from one service center or, conversely, how many tielines to how many different service centers are needed? The complexity increases geometrically with the number of concurrent users.

There appears to be no rationale to justify a vast interlocking multiple time-shared network. The programs (software) are portable and easily duplicated. All users have several large and identical (or at least compatible) data processing centers, so a trajectory program developed by JSC could be adapted to run on Langley's computer. The same can be said for other specialty programs (i.e., ground truth site scheduling, ground traces, expendable profiles, etc.). With this approach, all the needed software (applications programs) are available to a broad spectrum of Spacelab users, are accessible on a short turnaround basis, and can be reiterated as needed with only the user's data processing center running time as a recurring or mission-unique cost.

In addition, if the user's data processing center is configured as a time-shared multi-programmed service, with remote terminals in convenient locations, the operating cost would be further reduced. Such complex calculations as plotting the subsatellite ground trace and ground truth site viewing opportunities become no more difficult than using a pocket calculator. The development of activity schedule optimization software, like Langley's Manned Activity Scheduling System (MASS), into interactive (i.e., man-directed), conversational language tools, would enhance the applications-oriented mission analysis effort.

It is recognized that some non-recurring costs will be incurred in the adaptation/initialization of applications programs at various user centers. But, these non-recurring costs will be significantly less than those that would result if each user developed his own applications program library. In fact, if the proposed sharing of applications programs is not adapted, it is doubtful if Spacelab users would develop their own. The tasks would either be performed with a laboriously manual technique, or sublet to other centers with the resultant unacceptable time delay between iterations, which was discussed previously.

Mission Operations

The control of a mission is a combined and cooperative activity from launch through touchdown. The LS is the director of launch and landing operations; post-launch (launch tower clearance), on-orbit, and entry operations of the Shuttle/Orbiter are monitored and directed from the Mission Control Center (MCC) at JSC; flight data dissemination is the responsibility of GSFC; on-orbit experiment operations are monitored and controlled by the Spacelab user in conjunction with the PI's; and monitor and control of the Spacelab systems is concept-dependent. The first three segments of mission control (LS, MCC, and GSFC) are being planned and developed to support the entire Shuttle traffic model. The last two segments are of specific interest to this study and will influence the composite mission control approach.

User-PI Mission Support. Monitor and control of on-orbit experiment operations by the user-PI will require real-time down-link and up-link communications to evaluate on-going activities and experiment data in order to advise (or redirect) the payload specialists and to coordinate all ground truth site activities. A mission support facility is required to provide these services.

For Spacelab payload programs such as the ATL, the mission support facility should be at the user center. The ATL's broad spectrum of experiments and numerous PI's involved, plus the multi-flight-per-year/long-duration program preclude the approach of sharing a general-purpose/common-usage Spacelab payload monitoring center. Also, access and proximity to the PI's laboratories are essential for two reasons: (1) the PI need not relocate for the duration of the mission; and (2) the PI may be able to simulate/duplicate contingencies in his lab that may arise during a mission, and devise work-arounds/solutions to these contingencies. The proposed proximity of the mission support facility would permit the PI's to either be in attendance only during the operation of their experiments or be "on call" in case of contingencies. Real-time mission planning can be more readily and effectively accomplished if a mission monitoring/control facility is located at the Spacelab user center because of the PI's direct access to mission data and the proximity of their labs.

In this study, the mission support facility at the user center is referred to as the Operations Control Center (OCC). The key features of the OCC are active displays of factors that influence the mission. A simulated real-time and projected-time ground-viewing circle that follows the Orbiter ground track and has ground track site locations, aircraft flight patterns, cloud cover, etc., superimposed on the display is recommended. Control and display consoles for real-time, quick-look data reduction and display are also recommended. Direct voice and television communications between the OCC and the payload specialists are also included. This capability, coupled with the previously defined capabilities associated with mission analyses and planning activities will facilitate the direct participation of the PI's in the flight and, if necessary, permit effective re-planning during the flight.

It is recognized that the PI's and user center cannot accomplish mission monitor and control autonomously. Direct and continuous communication with the other involved control centers is required. Communications links with the MCC at JSC and, where appropriate, the operator of the Spacelab systems are also required to integrate both crew activities and utilization of Orbiter/Spacelab resources. At least one representative of the user center is stationed at non-user mission support centers for the duration of each flight.

Spacelab Systems Mission Support. Except for Concept V, the Spacelab support systems are the responsibility of a center other than the user. In Concept I, the integration center is the owner/operator of the Spacelab systems; in the remaining concepts, the LS is the owner/operator. The Spacelab support systems functions would be included in the OCC for Concept V. It is assumed that in Concept I a mission support facility would be at the integration center. In the remaining concepts, it is assumed that the Spacelab systems mission support would be co-located and integrated with the Shuttle/Orbiter mission support at JSC.

Mission Data Dissemination. The currently defined technique for relaying data between the Orbiter and the ground during a flight is via a Tracking and Data Relay Satellite (TDRS) system. Depending upon Orbiter altitude, almost continuous communications can be achieved with only one receiving/transmitting ground terminal. The proposed ground terminal of the TDRS is at White Sands, New Mexico.

Communication between the TDRS ground terminal and the various users of the Orbiter and the Spacelab is currently being studied by GSFC. If communications are only required between the TDRS ground terminal and JSC, a dedicated microwave link could be considered. But the dispersion of Shuttle and Spacelab users precludes microwave links and/or leased lines (bandwidth-dependent) from the TDRS ground terminal to all potential users because of the agency costs involved.

It is anticipated that during the Shuttle era, domestic geosynchronous communications relay satellites (DOMSAT) will be in operation. Preliminary evaluations indicate that it is feasible to relay flight data from the TDRS ground terminal via a DOMSAT to all potential users and the Orbiter/Spacelab operators in the Continental U.S. This data transfer can be accomplished by using only one DOMSAT transponder channel. Current planning indicates that the monthly lease rates would be of the order of $40 thousand and would be the least costly from a mission-unique or recurring standpoint. Installation of DOMSAT ground terminals at user sites must also be considered.

As the final flight data dissemination technique must reflect the requirements of all participants of the Shuttle/Spacelab programs, techniques other than use of a DOMSAT may be adopted. But, for purposes of this study, it is assumed that the DOMSAT approach is practical and compatible with the requirements of the operators and users of the Shuttle and the Spacelab.

System Engineering

The preferred approach to support function system engineering tasks is based upon computer-aided analysis, design, and recordkeeping. The definitization of the accommodations and capabilities of the Orbiter and Spacelab during their operational era will permit the standardization and, thus, the computerization of significant portions of the system engineering tasks.

System Requirements and Analysis. Standardized formats for the identification of experiments requirements can be developed. Performance requirements such as on/off cycles, power and cooling, data management, command and measurement lists, and operating instructions for common payload support can be synthesized in a format that will facilitate computerized compilation and integration in a manner similar to the integration of the composite on-orbit payload specialist activities by the MASS program. Experiment electromagnetic radiation characteristics that are required to evaluate potential EMI problems should be formatted such that computer-aided analysis can be accomplished. The Orbiter-cargo and integrated Spacelab checkout activities are relatively constant from flight to flight. The associated systems and interface verification test procedures can be standardized and, thus, these procedures can be computerized.

System Design. Standardized rack and pallet accommodations permit the use of computers in determining and allocating equipment locations and volume. Required view-angles and clearances should be included in the computer-aided design layouts. Automated wire lists and signal path routings should be developed. Mass and center-of-mass constraints of both the Orbiter and Spacelab will be well-defined to the user. A computer program should be developed which will compile payload mass characteristics, calculate the center of mass, and assess the compatibility of the payload with Orbiter/Spacelab constraints.

Systems Records. A significant quantity of system engineering manpower can be expended on the manual maintenance of test procedures, limits, documentation, configuration management, and other recordkeeping functions. Although all of these items must initially be generated manually the changes, revisions, updates, additions, deletions, and substitutions can be more readily and cost-effectively accomplished by computerization. Wherever possible, all recordkeeping functions should be computerized.

Mission-Unique Software Requirements

Throughout the discussion of payload integrator responsibilities, the dependency upon automatic processors (computers) to accomplish the support function tasks in an efficient manner was emphasized. In addition to the utilization of computers in accomplishing support function tasks, computers will also be utilized in the conduct of the mission operations. Thus, software must be generated for each mission. The required/recommended mission-unique software and the approach to validation of the software are delineated in subsequent paragraphs.

Software Classifications

Eight classifications of software associated with mission operations were identified. The potential applications of each of these classes is also indicated. The eight classes are as follows.

1.0 FLIGHT OPERATIONS. This is the software resident in the on-board computer that performs the functions of command, control, and data handling. These functions may be automated (pre-programmed), semi-automated (crew-directed) or remote controlled (radio command).

2.0 CHECKOUT/PERFORMANCE MONITORING. This software is used to acquire engineering data, configuration status, comparison to pre-selected tolerance or conditions, develop caution/warning/advisory signals, etc. This software would be resident in the Spacelab on-board computer during flight, and may be resident in a ground computer during the test and checkout ground operations.

3.0 FAULT ISOLATION DIAGNOSTIC. This software is similar to Category 2.0, but is much more extensive and much less automatic. Under nominal conditions it is retained in the ground data base and is only called when trouble occurs. Then, it may be applied on the Spacelab on-board computer (in flight) or by a GSE computer (on ground). While this may be well developed for the support module and other support subsystems, it is not recommended for experiments.

4.0 TEST AND VALIDATION. This software is used to prepare, test, debug, and validate the three previous software classes. It would be resident within the computer that supports the preparation of the three classes of software. It also includes compilers, assemblers, translaters, interpreters, and the programming language itself.

5.0 ORBITER SUPPORT. This software is resident in the Orbiter computer to provide correlation data (navigation, orientation, etc.) to the Spacelab data handling operation upon demand. Also in this category are the Orbiter performance monitoring and caution/warning backup.

6.0 REPAIR/REFURBISHMENT. This software is used to evaluate Spacelab telemetry data to predict what maintenance actions are required, including logistics and resource allocation. It is resident in the ground data base complex(es). This software should be well-developed for support systems, but it is not recommended for experiments.

7.0 DATA REDUCTION. This software is used to sort, merge, record, print, or otherwise prepare the flight data for disposition to the principal investigators. It also includes the real-time reduction for mission control. Similar programs may be in several different ground-based computers.

8.0 DATA ANALYSIS. This software is used to analyze the raw experiment data and could include statistical or trend data calculations. This software is used during postflight activities, and may be resident in several ground-based computers but not in the Spacelab on-board computer.

The development, test, and validation of the software is a significant factor in the integration cycle. The software related to experiments is a recurring cost--new software must be provided for every mission. The development, test and validation of fault isolation diagnostic and repair/refurbishment software for experiments is not recommended because of the variation of experiment equipment from flight to flight. But the remaining six classes of software are considered mandatory for efficient operations. Also, the development of the basic program for these six software classes need only be accomplished once. Mission-unique variations can be accommodated within a basic program, but retest and validation will be required.

Estimates for software development, testing, and validation run as high as $80 to $100 per statement (FORTRAN) for a typical memory-limited computer system. NASA (particularly JSC, KSC, and MSFC) has conducted intensive studies to determine more efficient and less costly techniques to develop software. The NASA recommendations from the studies, which are proposed for incorporation in the Spacelab integration process, are summarized below. The essence of these recommendations is characterized by developing tools, techniques, and architecture so that the ultimate user can prepare his own application program.

1. The user-programmer should not need to be aware of the intimate details of how the computer works: The internal executive and operating programming should be adequate to select and allocate resources, direct traffic, and manage the machine configuration, and not lose anything.

2. The programming language should be English: Limited vocabulary and constrained syntax are acceptable but mnemonic operating codes must be minimized.

3. The software shall be modularized: The data to be operated on should be separated from the instructions that sequence the operations.

4. Use a large memory machine: Shortage of memory space has been identified as a prime factor in elevating software costs. No software prepared in other than machine language can be efficient in memory space utilization--so more space is needed.

5. Provide adequate diagnostic and editing programs: This is how you "debug" a program, and should be part of the purchase cost of the machine.

6. Perform the program writing, assembly, compilation and debugging on the actual machine. The use of emulators and translators, to make one machine act like another, adds to the cost and adds one more risk.

7. Provide macro instructions (for example, a square-root function key) for complex internal routines. The emphasis is on English-common scientific notation--not mnemonic codes.

Software Test and Validation

All software is prepared in several steps. First, the individual routines and subroutines are written, which is a manual operation. These routines are coded and read into a computer. The computer has resident software that interprets the source code into assembly code. The assembly language coded routines are then compiled--i.e., put together in the proper sequence--and reduced to the target machine language code. This "program tape" (or card deck) is then ready to load into the using machine.

The "program" would then be tested and debugged. Additional software consisting of one or more test problems (with verifiable results), a diagnostic routine to determine what went wrong, and an editing routine so that what was wrong can be fixed are required for this operation.

When all the fixes are in and the test problems run correctly, the revised program is recorded, printed, and documented. If this program is now loaded into the target machine and the same test problems (or actual situations) can be run correctly and accepted by the user, the program is considered "validated."

The use of a source other than the payload integrator to test and validate software involves two transfers of responsibility, both entailing a risk of misinterpretation. First, the user must educate the programmer in the intricacies and operating idiosyncrasies of his experiments; and second, the programmer must educate the user on the capabilities, limitations, and constraints of the developed program.

The recommended approach for the test and validation of ATL Spacelab software is shown in Figure 3.2-1, and is analogous to the procedures for Orbiter computer software. Appropriate language, compiler, diagnostic and editing tools are provided by the contractor as part of off-line computer procurement. The computer executive program, operating system and file management software, display format "skeletons," etc., are also provided. A variety of applications modules, selected control or computation algorithms, etc., are also available.

The PI provides data modules to the payload integrator which customize the application modules to a specific function. The PI prepares his input on several standard format data sheets--typically, a measurement list, a procedural list, a telemetry list, a tutorial page, etc.

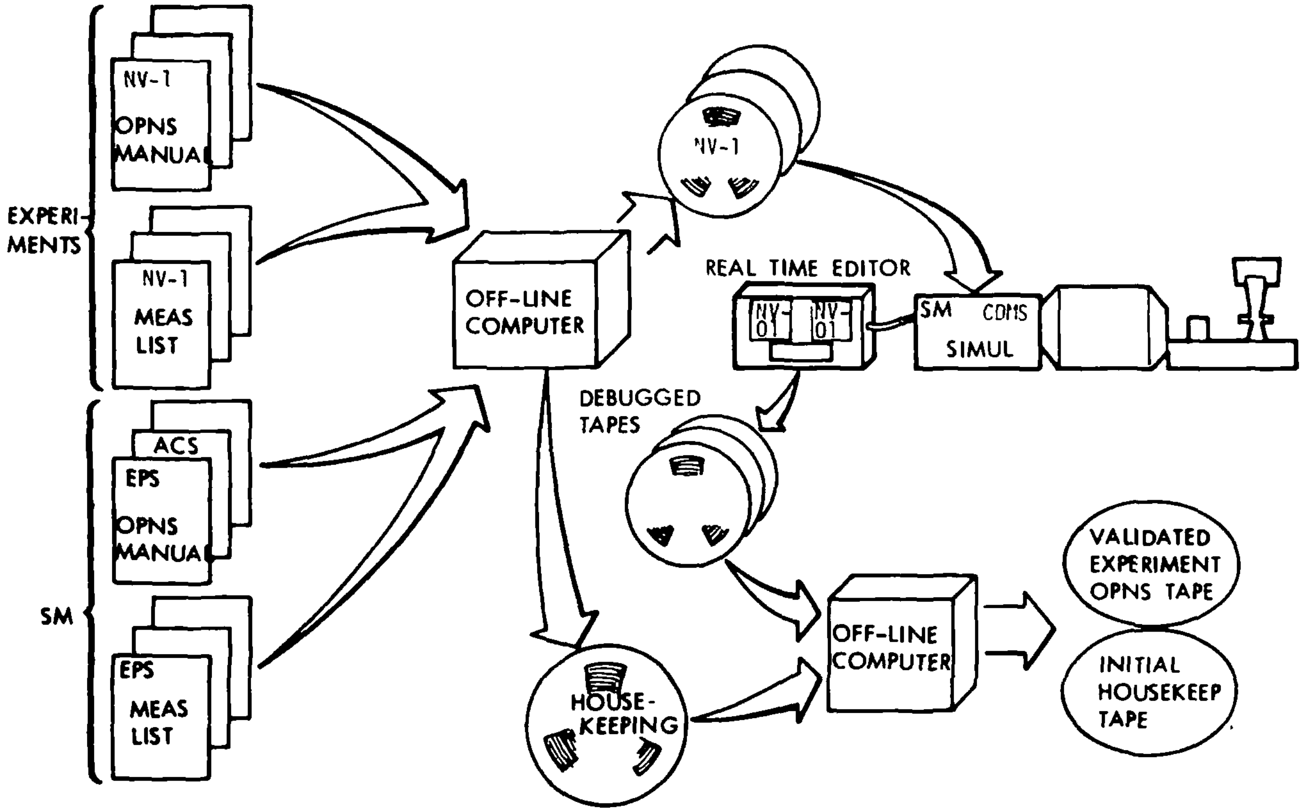

Figure 3.2-1. Spacelab Payload Modular Software Test and Validation

The payload integrator accepts these data sheets from each PI and uses them to assemble a first-cut tape wherein the experiment and associated support subsystems are merged to one operating routine. This routine (applications and data modules) is loaded into a simulator of the Spacelab Control and Data Management System (CDMS) along with the executive and operating system software, concurrent with the installation of that set of experiment equipment.

In this approach, the "debugging" of the operating routine is accomplished during experiment installation and test; editing and modification (only the data module) is done on site by means of a real-time editor which is part of the test complex but not part of the CDMS. The validated data modules (one for each experiment) are then assembled (off-line) into a mission tape. A similar process would prepare the Spacelab "housekeeping" tape at the next level of assembly.

This approach for the test and validation of Spacelab payload software minimizes the transfer of software requirements and responsibilities and also reduces the required number of validations. Control of the configuration of the CDMS simulator will virtually eliminate incompatibilities between the flight operations software and the flight hardware.

The other five applicable Spacelab payload software classes can also be tested and validated with this approach. In-flight checkout and performance monitoring software is an integral part of the flight software package and should be used during the testing of experiments. The real-time editing capability will permit rapid changes to limits and set-up/calibrate routines. Although the test and validation software is not directly applicable to flight operations, it will be used/tested/validated during the testing and integration of experiment equipment. Data reduction and data analysis software can be evaluated by using the data from the tests with the CDMS simulator. Orbiter support software can be tested and verified in a manner similar to that illustrated in Figure 3.2-1. Instead of the CDMS simulator, an Orbiter simulator is used in conjunction with the Spacelab flight hardware.

Support Function Responsibilities

The basic responsibilities of each center were initially established by the assigned ownership of the modules/racks/pallets that was part of the differentiation between candidate processing concepts. These ownership designations established the center responsible for the ground and flight operations of each individual Spacelab flight element (SM/EM shell, rack/rack sets, systems igloo, and pallet). But the responsibilities for the interfaces between elements and integrated sets of elements were not part of the initial concept definition. Support function tasks include these interfaces and integrations and the responsibilities are concept-dependent. In order to develop the total support function manpower and personnel requirements for each center for each processing concept, responsibilities for the tasks that involve interfaces and integrations must also be established.

As the same set of support function tasks is required regardless of the processing concept, then the effort required to perform the basic task is the same for all concepts. In the operational phase of a Spacelab payload program, each center (user, IC or LS) would be capable of conducting any of the basic support function tasks just as effectively as any other center. The delta task efforts that are concept-dependent are a result of multiple center involvement in some tasks. Therefore, where applicable, primary, secondary and support responsibilities must be defined.

Responsibility Criteria

In order to identify the role of each center in support function tasks, responsibility criteria were established. These criteria are presented in Table 3.2-1. The two principal themes of the criteria are (1) maintenance of owner cognizance, and (2) configuration control.

Owner Cognizance. PI/user involvement is not only desirable, it is the most efficient technique to accomplish all integration and checkout activities. The unique equipment in each flight is the experiment hardware. The associated expertise and the authority to approve or disapprove the integration and checkout of the payload remains with the owner of the experiment equipment--the PI/user.

Table 3.2-1. Responsibility Criteria

DRIVER	OWNERSHIP	CONFIGURATION MANAGEMENT
CRITERIA	MINIMUM PI/USER INVOLVEMENT INSTALLATION SITE PROVIDES WORKING CREW; USER PROVIDES PAYLOAD SPECIALISTS FLIGHT OPERATIONS SOFTWARE PREPARED BY EXPERIMENT INTEGRATOR GROUND TRUTH SITES OPERATED BY EXPERIMENT INTEGRATOR AND PI	INTERFACE CONFIGURATION CONTROL BY OWNER OF NEXT LEVEL OF ASSY. STRUCTURE FOR CONTINUING ATL PAYLOADS MODULE OWNER PROVIDES HARDWARE MODIFICATIONS CPSE CONTROL AND INVENTORY BY OWNER OF NEXT LEVEL OF ASSY.

The working crew should be made up primarily of on-site personnel. Procedures, equipment, maintenance cycles, etc., will vary from site to site. Therefore, the most efficient technique is to use the owners of on-site GSE and facilities. This approach does not preclude participation by personnel from other centers during the test and operations activities. The development of test procedures is included in support functions. Personnel that assist in the preparation of these procedures will frequently be from a center other than the center actually performing the tests. Representatives from the supporting center should be present during the tests. Also, the payload specialists, which may be the PI's (equipment owner) or their representative (equipment operator) are an integral part of the test team and will be involved in all tests and operations.

Because the most dynamic software requirements are related to experiment operations, the experiment/payload integrator must be responsible for the test and validation of the flight operations software. This software must reflect the composite experiment requirements. Since these requirements are developed by the experiment integrator, the implementation of the flight operations software must be under the cognizance of the experiment integrator also.

This approach does not violate the concept of flight hardware ownership. Software is considered a deliverable end item just like any hardware end item. Therefore, software can be owned by one center and the flight computer can be owned by another center.

Ground truth sites require an integrated coordination effort. Although the PI will stipulate his requirements and may even operate a truth site, the interrelationships and interdependencies indicate that the integrator of the experiment flight hardware also integrate the truth site activities.

Configuration Control. It is impractical for the owner of one level of assembly to control the interface with a higher level of assembly because each succeeding higher level of assembly of the payload/Spacelab/Orbiter is more standardized. That is, each higher level of assembly must be compatible with a broad spectrum of potential users. Changes at higher levels of assembly could impact other users that a lower assembly owner would not even be aware of. Responsibility for the configuration control of interfaces must be maintained by the owner of the highest assembly level involved.

Examination of a particular ATL payload may support a unique responsibility matrix. But tailoring the matrix to each payload would not only be costly, but also result in confusion. The matrix must reflect a constant/repeatable approach that can be readily understood and implemented by a broad spectrum of experimenters/users.

Hardware modifications must be controlled by the owner of the equipment (experiments/SM-EM shell/racks/pallet) for the same reason interface control must reside with the highest level of assembly involved. Only the hardware owner has the visibility to determine the potential impact of changes and, thus, must retain/maintain configuration control of that hardware.

It is anticipated that common payload support equipment (CPSE) will be made available to Orbiter and Spacelab users. This equipment is not normally included in the Orbiter/Spacelab, but compatibility has been demonstrated. The CPSE would include equipment such as oscilloscopes, spectrum analyzers, counters, tape recorders, and signal generators. It would be impractical for every Spacelab user to maintain an inventory of Orbiter/Spacelab compatible CPSE. Therefore, the configuration and inventory control of CPSE is the responsibility of the Orbiter/Spacelab owners.

Key Interfaces

The results of the application of the previously presented responsibility criteria to key integration and checkout interfaces are presented in Tables 3.2-2 and 3.2-3. Primary, secondary, and supporting roles for centers involved in each interface are indicated.

Support function interface responsibilities (Table 3.2-2) reflect the role of the IC as the experiment/payload integrator and owner of Spacelab hardware in Concepts I and II. In other concepts the user assumes the responsibility for experiment/payload integration. IC responsibilities in Concept III reflect the ownership of the racks and pallet. The role of the LS is always in a secondary or supporting capacity. Participation of the LS in mission planning and Orbiter software requirements definition reflect ownership/operation of the Orbiter by the LS. Participation of the LS in other support function interfaces reflect LS ownership of the Spacelab support systems. The user is always responsible for the training of the payload specialist in conjunction with the payload integrator and/or the owners of the Spacelab hardware.

Table 3.2-2. Key Experiment Integration Support Function Interfaces

	MISSION PLAN	OPER INSTR	PI/CREW TRAINING	GROUND SUPPORT	SYSTEM ANALYSIS	SYSTEM DESIGN	ORBITER SOFTWARE REQMTS
CONCEPT I	IC/LS	IC/U	U/IC	IC/U	IC	IC	IC/LS
CONCEPT II	IC/LS	IC/LS/U	U/IC/LS	IC/LS/U	IC	IC	IC/LS
CONCEPT III	U/LS	U/LS/IC	U/LS/IC	U/LS	U	IC	U/LS
CONCEPT IV	U/LS	U/LS	U/LS	U/LS	U	U	U/LS
CONCEPT V	U/LS	U	U	U	U	U	U/LS

NOTE: -/-/- = PRIMARY/SECONDARY/SUPPORTING

Table 3.2-3. Key Experiment Integration Hardware Interfaces

	R/P MODS	SM MODS	CPSE	EXPERIMENT INSTALL	SPACELAB INTEG	CARGO INTEG	SL-OPNL SOFTWARE
CONCEPT I	IC	(IC)	IC/LS	IC/U	IC/U	LS/IC/U	IC/U
CONCEPT II	IC	(LS)	IC/LS	IC/U	LS/IC/U	LS/IC/U	IC/U
CONCEPT III	IC	(LS)	IC/LS	U/IC	LS/U	LS/U	U
CONCEPT IV	U	(LS)	U/LS	U	LS/U	LS/U	U
CONCEPT V	U	(U)	U/LS	U	U	LS/U	U

NOTES:

- -/-/- = PRIMARY/SECONDARY/SUPPORTING
- (-) = LITTLE IF ANY MODS OTHER THAN CPSE

Responsibilities for hardware interfaces directly affect the preparation of test procedures and the configuration management of the payload/Spacelab/Orbiter. The responsibility matrix for hardware interfaces (Table 3.2-3) reflects the ownership of the flight hardware and/or the highest level of assembly involved. The LS has primary responsibility for Orbiter cargo integration in all concepts as a result of its ownership/operation of the Orbiter. Similarly, the LS has primary responsibility for Spacelab integration in those concepts where it owns the SM. User and IC primary responsibilities also reflect flight hardware ownership. In addition, the center responsible for payload integration is reflected in the designation of the primary center for Spacelab software. In all concepts, the user is directly involved in all levels of integration. Responsibility for experiments is not transferred as the level of assembly progresses. This hardware responsibility is also reflected in the IC's role in the various levels of hardware integration.

Based upon the responsibility criteria and the designation of primary, secondary, and supporting roles of the center in support functions and hardware interfaces, manpower estimates for each task, each center, and each concept were developed. The manpower estimates for mission-unique support functions are developed in Volume III of the report.

APPROACH TO SUSTAINING SUPPORT FUNCTIONS

Initially, an attempt was made to identify specific management/administrative tasks and responsibilities for the sustaining activities associated with the processing of Spacelab payloads. But the characteristics of the individual tasks are not amenable to the development of manpower estimates that can be attributed to the processing of _a_ Spacelab payload. Also, management responsibilities include the direction of operations at a center other than just the integration and checkout of a Spacelab payload. Scheduling of sustaining activities is also impractical because these activities are continuous and relatively independent of flight rate. Therefore, the approach selected to definitize sustaining support functions was to derive a management organization at each center that was tailored to the requirements of each processing concept.

User Center Organization

Figure 3.2-2 presents the derived user organizations for the processing concepts. Line organizations that report directly to the ATL Program Office include three principal activities: advanced mission/experiment planning, experiment development, and integration and checkout. Integration and checkout activities are expanded to reflect three major areas of effort: operations analysis, systems engineering, and test and operations. Only managers and their secretaries are considered to be sustaining personnel. Lower levels of supervision are flight-rate dependent and directly attributable to the processing of a specific payload. Note that the test and operations organization is not applicable for Concepts I, II and VII. All processing of flight hardware is performed at a site other than the user's site.

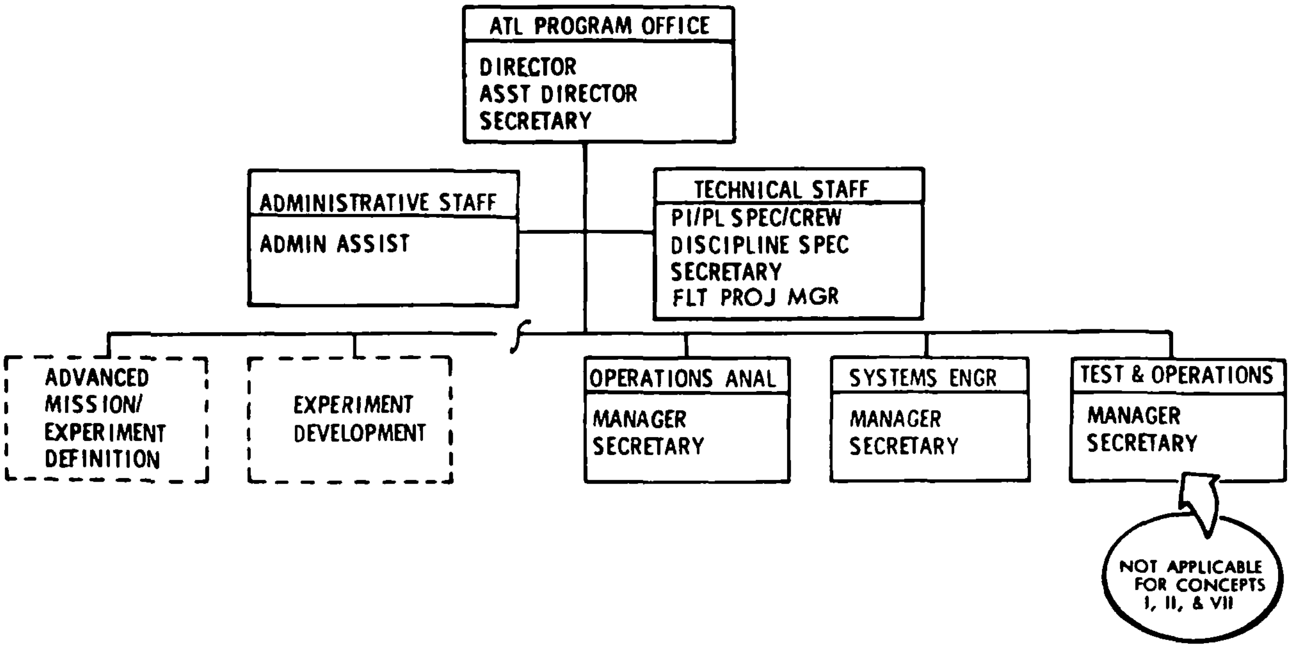

Figure 3.2-2. User Center Sustaining Organization

A technical staff is indicated, which transcends both all the program activities and the line organizations. A cadre of payload specialists is indicated. These personnel will be involved in all facets of the ATL program and, thus, their contributions/time cannot be attributed just to integration and checkout.

In addition, a cadre of experiment discipline specialists is identified. As the ATL program involves six major discipline/technology areas of endeavor, one individual was identified for each area. The role of the discipline specialists is to provide the liaison and coordination between experiment equipment development activities and integration and checkout activities.

The one group of personnel in the sustaining organization that can be attributed to the processing of a specific payload is the flight project managers. The function of a flight project manager is to coordinate and direct all the effort at the user center to integrate and check out a payload; he is the representative of the program office for a specific payload. The flight project manager is also the primary interface with management from other involved centers.

An administrative staff is also indicated for maintenance of programmatic records such as schedules and costs.

Integration Center Organization

Figure 3.2-3 illustrates the organization at the integration center that is required to manage/administer the integration and checkout activities at that center. The line organizations are the same as those of the user center. This organization is applicable only in Concepts I, II, III, VI and VII. (IC is not involved in IV, VIII and V.) In addition, the operations analysis line organization is only applicable in Concepts I, II, and VII. The user center assumes the responsibilities of this line organization in all other concepts.

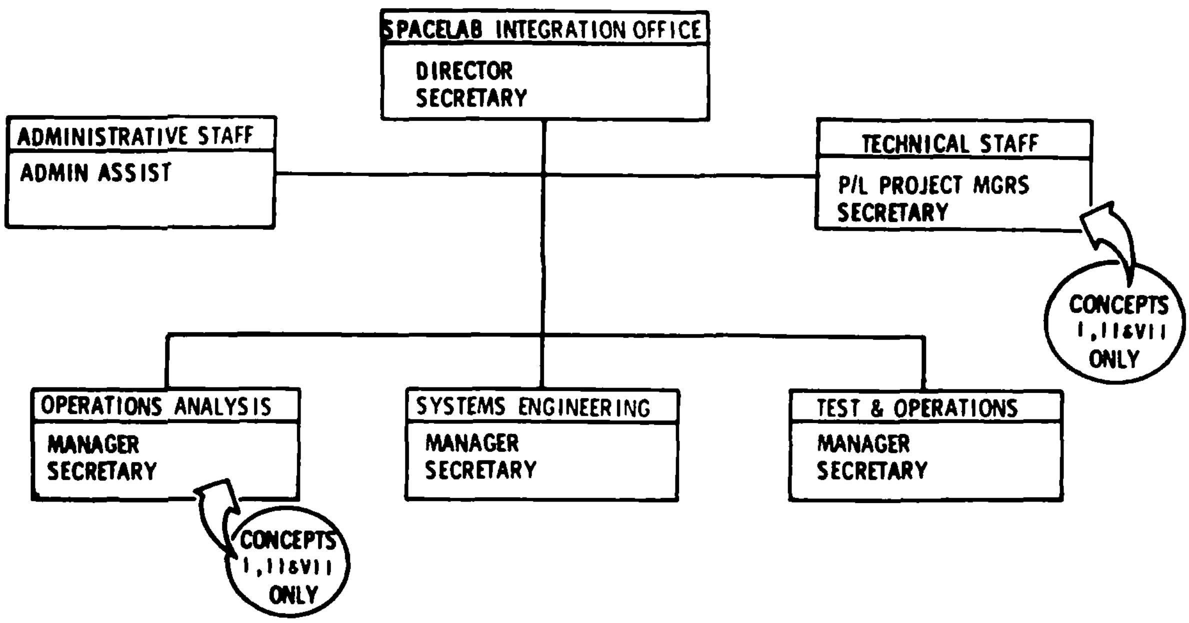

Figure 3.2-3. Integration Center Sustaining Organization

A payload project manager is identified in a staff position. The role of this manager is essentially the same as the flight project manager of the user organization. It is the responsibility of the payload project manager to direct and administer the required center resources to accomplish the integration and checkout of a Spacelab payload. One payload project manager is assigned/dedicated to each Spacelab payload being processed.

Launch Site Organization

The organization presented in Figure 3.2-4 reflects the launch site's role as owner/operator of the Orbiter in all concepts and, when applicable, the owner/operator of the Spacelab support module and systems igloo. Two of the line organizations are indicative of the two integration levels that occur at the launch site. Orbiter cargo integration is applicable in all concepts. Spacelab/payload integration occurs at the launch site in six of the eight candidate processing concepts. The procedures, GSE, and facilities associated

with these two integration levels will be significantly different. Therefore, separate line organizations were identified.

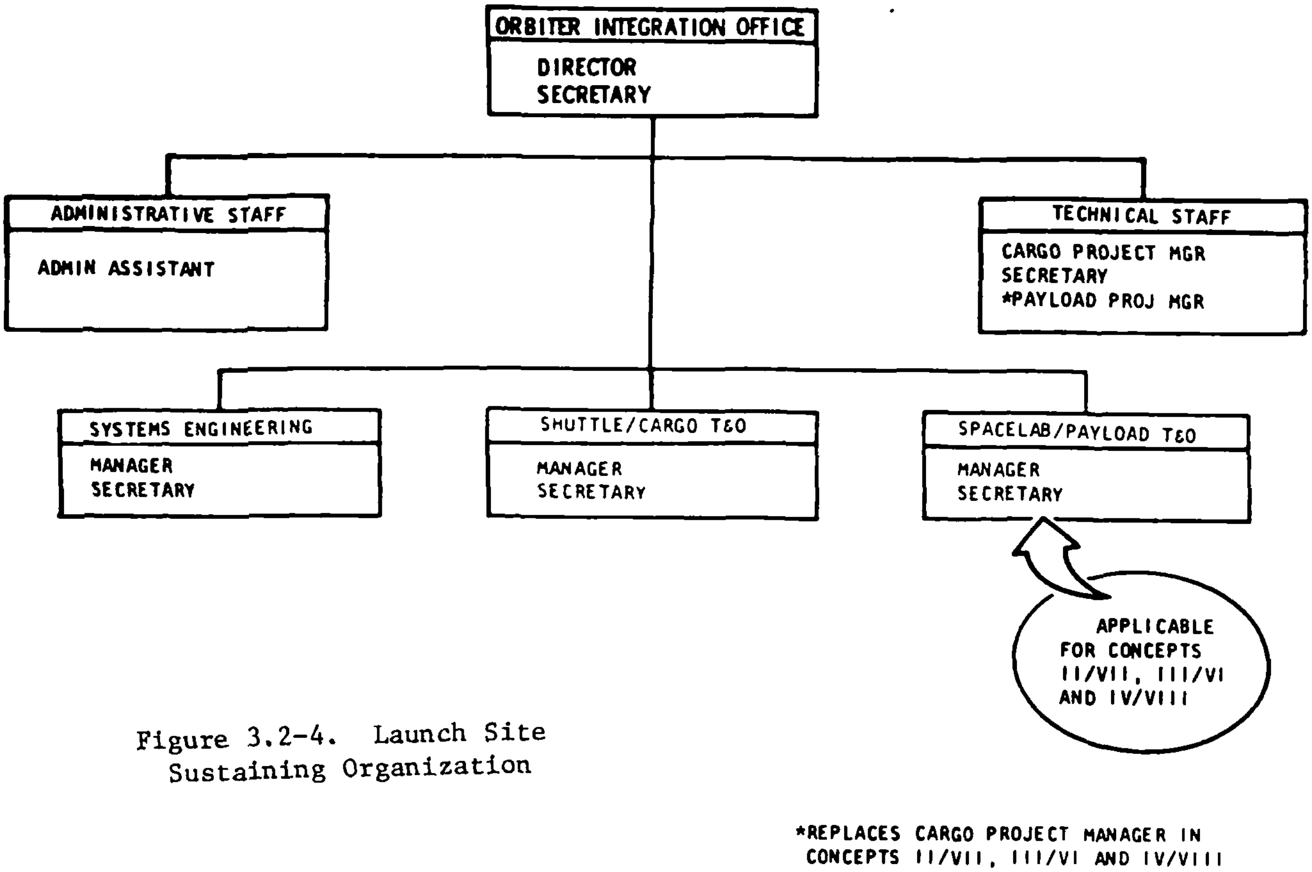

Figure 3.2-4. Launch Site Sustaining Organization

The systems engineering line organization is indicative of the launch site in the accomplishment of support functions. Operations analyses, mission planning, requirements definition, and design and fabrication of interfacing hardware are the responsibility of centers other than the launch site. A systems engineering line organization is required at the launch site to coordinate payload and cargo requirements and ensure compatibility between the payload, Spacelab, and Orbiter.

As the role of the launch site varies between concepts, two types of project managers were identified. In those concepts where the launch site performs only Orbiter/cargo integration, a cargo project manager is identified; in those concepts where the launch site performs both Spacelab/payload and Orbiter/cargo integration, a payload project manager is identified. This differentiation was established to avoid transfer of management responsibility at the launch site during the processing of a payload. The role of the launch site project manager is essentially the same as the integration center payload project manager and the user's flight project manager. That is, the launch site project managers will direct and administer the required center resources to accomplish the processing of the payload and Spacelab through that center.

APPROACH TO NON-RECURRING SUPPORT FUNCTIONS

Development of an approach to accomplish the non-recurring support functions is dependent upon two factors: the program plan of the Spacelab user and the basic data pack that will be available from the Spacelab manufacturer (ESRO/ERNO) and operations developer (MSFC). Each Spacelab user will derive a unique program plan that reflects objectives, schedules, and funding constraints. It is impractical to develop a generalized approach that will delineate phased activities to derive payload processing procedures, controls, software, GSE, and facility requirements. But the identification and definition of the support functions that must be accomplished prior to initiation of integration and checkout operations will provide the visibility to the user to develop a tailored program plan.

At the time of this study, the data pack to be developed by ESRO/ERNO and MSFC was in an evolutionary stage. Both the lists of documents, handbooks, software, etc., and the contents were changing. Therefore, based upon preliminary data from ESRO/ERNO and MSFC, assumptions were made as to the scope and detail of the data pack that will be available to the Spacelab user. The support function requirements to adapt the basic data pack to the unique applications of a user are directly related to these assumptions. In order to avoid cross-referencing between volumes of this report, both the assumptions pertaining to the basic data pack and the non-recurring support function requirements are presented in Volume III.

The only tangible recommendation to accomplish the non-recurring support functions is to perform the tasks with the nucleus of the systems engineering line organization that will participate in operational integration and checkout activities. This approach will facilitate a smooth transition from the development stage to the operational stage of integration and checkout. The synthesis of the WBS incorporated this approach. The WBS included the majority of the non-recurring support function tasks in the systems engineering group.

4.0 TEST AND OPERATIONS

In this section the second major set of integration and checkout tasks, test and operations, are established, defined, and optimized. The optimized checkout approach included the establishment of guidelines that emphasized functional ground testing of flight equipment in the same manner as the planned flight operations. A computer-aided technique that would utilize the capability of the on-board data management system (DMS) of the support module/systems igloo was the preferred approach.

The feasibility of the preferred checkout approach was evaluated in terms of the operational capability and the memory capacity of the DMS. Operational capacity was more than ample; additional mass memory (tape recorders) was required for reference data.

Use of support system/interface simulators during Level III integration was evaluated. A negligible effect in experiment hardware processing time resulted. The complement of support modules/systems igloos required to support the anticipated Spacelab traffic model was significantly reduced by the use of simulators. All developments of processing concepts reflected incorporation of support system/interface simulators during Level III integration activities.

Three categories of checkout requirements were evaluated: functional, environmental, and operational. Functional checkout requirements for both the Orbiter/Spacelab and the experiment systems were evaluated. Only functional testing of experiment systems and interface verification testing of experiments/Spacelab/Orbiter were identified as being required. The environmental checkout requirements were evaluated by analyzing the trends in recent space programs in terms of their applicability to the characteristics of the ATL Spacelab program. This effort evaluated the anticipated ATL/Spacelab environmental requirements and established a preferred verification approach. It was recommended that all integrated payload environmental certifications, except electromagnetic compatibility (EMC) be accomplished by analysis/similarity techniques; empirical tests were required only for EMC certification. Operational checkout requirements were analyzed in terms of the potential processing cycle impact of payload cleanliness constraints and shipping/transportation modes. These two areas were evaluated because of their influence on the test/retest requirements as well as installation/assembly procedures and sequences.

A composite set of test and operations requirements was derived and is presented in matrix format. The appropriate integration level, where the test/checkout requirement is satisfied, was also identified.

The three-step approach utilized to establish the detail flows is delineated in Subsection 4.2. The establishment of top-level functional block diagrams that reflect hardware processing scenarios of the test and operations activities for all eight processing concepts is presented. The expansion of these block diagrams to detailed flows and activity data sheets (presented in Appendix D) is illustrated. The time estimating technique for the detail flows and their utilization to define an integrated flow sequence is presented. The integrated flows for each concept are evaluated and the summaries of processing times compared. Based upon a single-shift five-day work week, the processing times of the candidate concepts are about six calendar months. Variations between concepts can be attributed primarily to handling/shipping requirements.

4.1 DERIVATION OF TEST AND OPERATIONS APPROACH

The approach adopted for the accomplishment of the test and operations activities is a key factor in minimizing both the recurring and non-recurring costs of the NASA for integration and checkout of Spacelab payloads. Two interrelated considerations are the minimizing of processing time and the maximizing of the utilization of equipment.

Checkout guidelines were established that emphasized the functional testing of the flight equipment in a manner analogous to the planned flight operations. Unique ground testing was minimized. Use of the on-board data management system during checkout was evaluated. With testing limited to functional operations rather than performance or capability evaluation, the on-board system was adequate and facilitated simultaneous software/hardware verification.

Use of simulators of elements of the Spacelab was evaluated. It was determined that the complement of required flight hardware could be significantly reduced with the use of simulators. Consequently, programmatic costs could also be reduced.

Functional test requirements were defined that reflect the operational nature of the Spacelab and Orbiter. The mission-unique activities are associated with experiment integration (Level III). Spacelab and Orbiter-cargo integration (Levels II and I, respectively) is relatively standard from flight to flight, and test activities should be limited to interface verification. Compatibility of interfaces was demonstrated during the operational development activities of these two programs.

Environmental testing of integrated Spacelab payloads was minimized. Based upon the fact that the environments that Spacelab payloads will be subjected to will be firmly established, individual experiment equipment environmental testing was recommended; only analytical techniques were recommended for evaluation of environmental effects at the integrated payload level of assembly. The one exception to the analytical approach was with respect to electromagnetic compatibility (EMC). Empirical testing will be required to assure EMC.

Operations considerations indicated that maintenance of appropriately clean environments during test and shipping/transporting activities will permit complete assembly and checkout of each level of assembly prior to mating with the next higher order of assembly. *Last-minute* installations and checkouts were minimized.

Use of the proposed 747 *piggyback* mode for transport of assembled Spacelab elements or the C-5A when only racks and pallets are involved, precluded the disruption of interfaces after verification. Retesting after major moves was limited to receiving-inspection type activities.

A composite set of test and operations requirements was derived. The accomplishment of each requirement in the checkout sequences for the various candidate processing concepts was identified.

OPTIMIZED CHECKOUT APPROACH

Basic guidelines for the checkout of a Spacelab payload were formulated. The factors to be optimized were defined and the resulting provisions in the checkout approach were identified. Alternate implementation techniques were evaluated and a preferred approach selected.

Checkout Guidelines

The development of checkout guidelines is illustrated in Figure 4.1-1. These guidelines reflect a test philosophy that stresses the verification of planned flight operations. Off-nominal or limit testing to assess the capability of equipment/systems should not be included in the integration and checkout activities of an operational program.

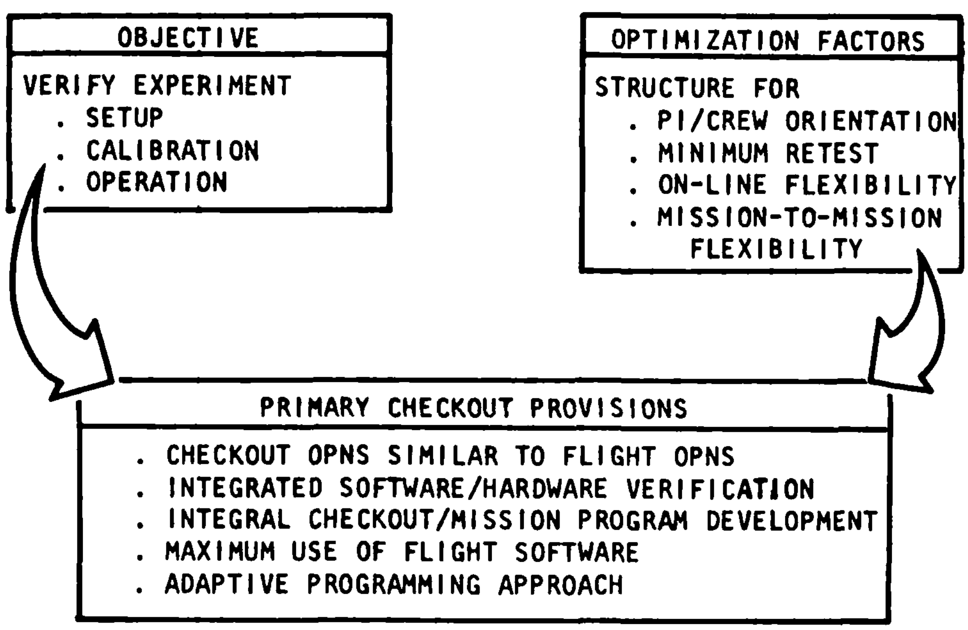

Figure 4.1-1. Checkout Guidelines

The assembly and integration of the several elements of the Spacelab include several intermediate checkout points wherein the installation is verified as being correct. These checkpoints start at the lowest integral assembly (the experiment) and progress through the rack/pallet and complete Spacelab to the Orbiter installation. The checkpoints should involve selected tests and operations performed to assure that all system elements achieve

experiment objectives. That is, the objective of the tests should be to demonstrate the capability to set up, calibrate, and operate the experiments.

The accomplishment of this objective is dependent upon the compatible operations of several subsystems that will be managed and controlled by the crew and aided by the on-board data management system. At the experiment level of assembly, the following elements are involved:

- Unique phenomena sensor
- Supporting instrumentation
- Supporting subsystems
- Payload specialist crewmen
- Spacelab data management hardware
- Spacelab data management software

Higher levels of assembly and installation require these same elements with other elements progressively added:

- Rack and/or pallet equipment
- SM subsystem provisions
- Orbiter subsystem provisions

The several levels of assembly and integration will require a number of test operations. An optimum approach would be structured around the critical factors of (1) PI/crew orientation, (2) minimum retesting, (3) on-line flexibility, and (4) mission-to-mission flexibility (see Figure 4.1-1).

The payload specialists should know how to operate the experiment equipment (procedures) and understand the phenomena being investigated. The source of their orientation is the principal investigator (one or more), and they would become familiar with the experiment by participating and operating the equipment at the PI's facilities.

In general, the payload specialists will have flown on previous missions (especially in the case of a continuing program such as the ATL), and will be competent in the operation of Spacelab systems. The mission-unique orientation will be the adaptation of the standardized Spacelab systems to command/control the operations of a particular payload. The checkout procedures should be devised to provide this orientation.

In past space programs, it was common practice to verify flight hardware operations with checkout software, and flight software with simulated hardware. Invariably, major incompatibilities occurred when the two end items of flight equipment were integrated. In Section 3.2 of this volume, a technique for parallel development of flight software and hardware that culminated in simultaneous checkout and verification was delineated. The technique is proposed as a basic approach to optimizing checkout techniques. Serial test time is reduced, retest is minimized, and the associated support functions of test procedures preparations, test reports, GSE requirements, configuration control, etc., are minimized.

As the primary objective of checkout is to demonstrate the mission operability of the systems, the checkout approach should reflect the planned mission. Checkout and mission development should not be discrete entities; they should be accomplished as an integrated set of tasks. One technique to facilitate this

integration is to utilize flight procedures and flight software wherever possible.

Revisions to equipment, procedures, and software during the integration and assembly operations should be anticipated and reflected in the checkout approach. Capability for modifying the checkout approach should be included. Since a certain amount of the testing is controlled by the Spacelab data management system software, the checkout approach should incorporate a quick-turnaround capability in software preparation. In Section 3.2 of this volume, the inclusion of a real-time editor in the checkout station GSE was recommended.

Mission-to-mission flexibility is important to the achievement of low-cost multiple-mission operations. The checkout equipment, procedures, simulators, etc., should be implemented by an approach that can match the flexibility of Spacelab experiment payloads without extensive rework between missions. Adaptive programming will provide the required flexibility both during checkout and between missions.

The checkout approach model should provide for concurrent verification of software, hardware, procedures and interfaces to minimize both cost and time. The mission operations development and the checkout verification operations should be synchronized and adaptable. Since the objective of checkout is to assure in-flight operations, then checkout is very similar to in-flight, and would take maximum advantage of the flight control software prepared for the Spacelab data management system.

In addition to meeting the checkout objectives and guidelines, the checkout approach provides for on-line verification of the flight software. No on-line facility computer is required because the simulator with its flight-equivalent computer is used.

The integral software/hardware checkout approach provides the opportunity to perform an abbreviated mission simulation. It is recommended that the payload specialist crew members (the PI's or their representatives) use the checkout operations as a mission training activity. In this manner, the payload specialists will be getting flight hardware and software experience. In a continuing program, such as the ATL, the payload specialists will probably have flown on previous missions and their experience will be invaluable during the checkout activities.

Alternate Checkout Implementations

As shown in Figure 4.1-2, three approaches to achieve the checkout guidelines were evaluated. A manual approach would result in prohibitive in-process time. An automated approach would be very costly and would not meet several key goals in the checkout process. It would be of little use to the flight crew, and both on-line and mission-to-mission flexibility would be almost impossible to achieve. A computer-aided approach can be structured to meet all the checkout guidelines.

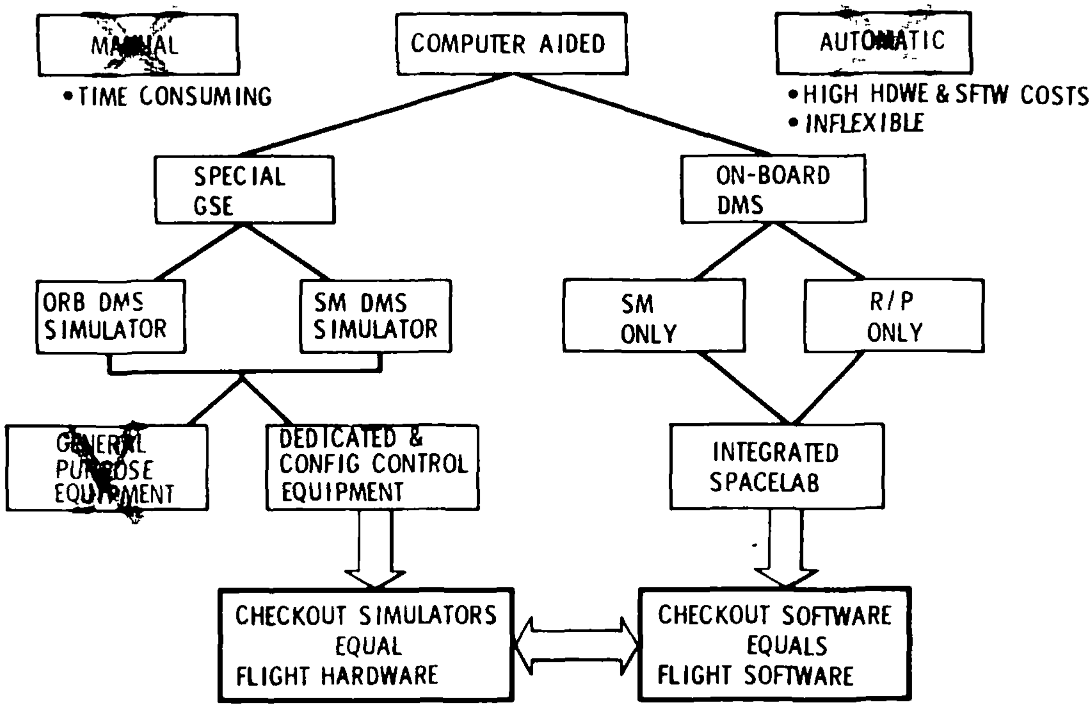

Figure 4.1-2. Alternate Checkout Implementations

Use of the on-board data management system (DMS) of the support module/systems igloo was evaluated to determine its capability to support the checkout of the support system and the integrated rack and pallet assemblies. (This evaluation is presented in subsequent paragraphs of this section.) Adequate capacity exists for such checkout and also integrated Spacelab checkout. Thus, the checkout software for the ATL/Spacelab can be incorporated in the SM computer. Flight software can be concurrently developed and verified with the checkout software or flight-equivalent hardware.

Use of the flight DMS during rack/pallet checkout is not recommended. The involvement times of the DMS, if it were used during Level III integration, would significantly increase the required complement of these equipments to support the anticipated Spacelab traffic model. (The evaluation of the use of simulators versus flight hardware is presented in subsequent paragraphs of this section.)

Special-purpose GSE/simulators were identified for both the DMS and the Orbiter interface. Use of general-purpose equipment in the simulators was rejected because of the problems invariably encountered when flight hardware is utilized at the next level of assembly and checkout. The recommended simulators are flight hardware equivalent. Configuration control of the simulators must be maintained. In this manner, problems at the next level of integration will be minimized.

FEASIBILITY OF CHECKOUT APPROACH

The selection of the preferred checkout approach was contingent upon the capability of the Spacelab data management system (DMS) and the practicality of the use of a DMS simulator during Level III integration. Both of these potential limitations are discussed in this subsection.

Data Management System Compatibility

Two aspects of the data management system requirements were evaluated: (1) operations, and (2) main memory. The capability of the DMS to accommodate the requirements was assessed. Checkout implications were defined.

DMS Operations Compatibility

At the initiation of this study, only one computer was included in the DMS. As of October 1974, three computers were identified: one for support systems, one for experiment operations, and an on-line spare for either of the other two. As the final configuration has not been established, a conservative approach in the evaluation of DMS capacity was used. It is assumed that only one computer is available; therefore, the evaluation included estimating both support system and experiment system requirements.

Support System Requirements. There are seven support subsystems within the Spacelab:

1. Environmental Control Subsystem (ECS)
2. Command and Data Management Subsystem (CDMS)
3. Electrical Power and Distribution Subsystem (EPDS)
4. Structure Subsystem
5. Instrument Pointing Subsystem (IPS)
6. Software Subsystem
7. Common Payload Support Equipment (CPSE) Subsystem

At the time of this study, none of the above listed subsystems were adequately defined to estimate the required measurements and commands to operate them. The basic design/operations approach to the Spacelab support systems closely parallels the approach adopted in the Phase B Modular Space Station (MSS) preliminary design. Therefore, estimates for Spacelab subsystems operations requirements were extrapolated from MSS data.

The Modular Space Station was configured to support 6 or 12 men indefinitely and autonomously; the Spacelab is configured to support 2 to 4 mean for 7 days. Therefore, to be useful, the measurement and command estimates should be scaled down by a factor of 3 to 6. (MSS had six active habitable modules, each larger than the Spacelab.) Table 4.1-1 is a compilation of applicable MSS requirements. Table 4.1-2 presents the scaled-down estimates for the Spacelab.

Table 4.1-1. Space Station Measurements and Commands

Subsystem	Function	Time Criticality	Measurement		Command	
			Analog	Discrete	On-Off	Settings
EPS	Battery/inverter	1 second	40			4
	Battery charging	1 second	3.5K	96	1.5K	
	Primary bus	4 milliseconds	4	32	56	8
	Secondary bus	1 second	378		42	14
	SSCB	100 milliseconds	540	540	540	
		1 second	540	540	540	
ECLSS	Pumpdown and repressurization	1 minute	10	18	10	
	CO_2 management (D&S)	1 second	24	16	16	2
	O_2 partial pressure	1 second	2	2		1
	Humidity and contamination	1 minute	26	42	34	4
	Circulation and temperature control	1 minute	90		60	
	O_2-N_2 control	1 second	49	5	16	2
	Active thermal	1 minute	98	77	146	

EPS = Electrical Power Subsystem
ECLSS = Environmental Control and Life Support Subsystem

Table 4.1-2. Extrapolated Spacelab Subsystem Measurements and Commands

Subsystem Function	Time (seconds)	Measurements		Command		Measurements per Second
		A	D	D	A	
EPDS Inverter	1.0	10			4	10
Battery pack	1.0	50	10	20		60
Primary bus (28 vdc)	0.1	4	8	8		120
Secondary bus (6 voltages)	0.1	24	16	32		400
Circuit breakers	0.1	20	20	40		400
Circuit breakers	1.0	100	100	200		200
ECS/ARS CO_2 management	1.0	24	16	16		40
O_2 partial pressure	1.0	2	2		1	4
Humidity and contam.	60.0	26	42	34	4	1
Circulation and temp.	60.0	90		60		2
O_2-N_2 control	1.0	12	4	8		16
Coldplate	60.0	20	10	20		1
Structure						
Stress/mountings	60.0	20	10	20		1
Hatches, etc.	1.0		20	4		20
Subtotal						1275
Inst. Pointing						
Angles, etc.	0.1	12	24	24		360
CDMS						
Auxiliary and peripheral	1.0	20	20	40		40
Total		434	302	338		1675

EPDS - Electrical Power and Distribution Subsystem
ECS/ARS - Environmental Control Subsystem/Air Revitalization Subsystem
IPS - Instrument Pointing Subsystem
CDMS - Control and Data Management Subsystem

There were no comparable estimates for the instrumenting pointing subsystem (IPS), the tunnel, or common payload support equipment (CPSE). The information management subsystem of the MSS included self-test capability by built-in software. It was assumed that the Spacelab CDMS would have comparable capability. The tunnel measurements and commands were included within the structures estimates, and the CPSE was arbitrarily grouped with the experiment equipment.

The IPS is a multiple-axis platform mounted on the pallet to handle the instruments requiring more precise pointing stability than the basic Orbiter attitude control system. Thus, it must sense, compute, and control motions based upon the Orbiter reference. It is believed that this control loop mechanization will, because of the high iteration rate and double-precision computations, utilize a dedicated processor and not share the CDMS processor. Therefore, the assumption was made that checkout would require no more than the capability to command a selected attitude and measure a few outer loop parameters. These estimates are included in Table 4.1-2. Also, those status and on-off commands for CDMS auxiliary and peripheral equipment (e.g., closed-circuit TV and recorders) were added.

The operations estimates for Spacelab subsystems total 1675 measurements per second, and the total number of data points (sensors) is 736. The estimated number of commands is 338 (no rate). If 736 measurements and 383 commands are implemented by discrete, dedicated meters, lights, annunciators and switches the control panel will be very "busy", difficult to read, and expensive. For comparison, the Apollo Command Module main display console (3 panels) contained about 300 discrete components, and cost approximately $1.0 million per panel, per spacecraft. Therefore, the assumption was made that some form of multipurpose time-shared displays and control would be used, and discrete components would be limited to circuit breakers and clock-type displays.

In order to accomplish the data acquisition and performance monitoring function, six operations are required:

1. Request to data bus controller.
2. Accept data bus controller data block.
3. Fetch nominal, U.L., and L.L. values from memory.
4. Compare actual to nominal, and limits.
5. Store new value in memory block.
6. Access new value, nominal, U.L, L.L., and nomenclature for display processor.

The timing estimate for these operations, based upon a total of 736 measurements, is given in Table 4.1-3. Preliminary definition of the CDMS computer(s) indicates that in excess of 500,000 operations per second can be accommodated. Thus, the extrapolated requirements for support systems operations is about one percent of the computer capacity. The on-board CDMS is more than adequate to support the performance monitoring and thus the ground checkout operations of Spacelab support systems.

Table 4.1-3. Timing Functions

Operation	Microseconds
1. Request to DBC	2
2. Transfer 736 words	1,472
3. Fetch 736 words	1,472
4. Compare 2 and 3	1,472
5. Store 736 words	1,472
6. Access 736 x 6 words	4,416
Total	10,306

Experiment Systems Requirements. The previous analyses demonstrated that the Spacelab CDMS could support the integrated checkout of Spacelab support subsystems using about one percent of the specified capability of the on-board computer. The estimates were based upon the extrapolation of Modular Space Station support system requirements. There was no comparable measurement/command estimates for experiment systems. Therefore, two ATL experiments were analyzed to establish a probable measurement/command list. In both cases, about 30 discrete commands, and a similar number of measurements, were required to set up, calibrate and/or operate the system.

The specific data pertaining to one of the experiments, Laser Ranging, is presented to illustrate the compilation of the requirements for an on-line Spacelab payload. Figure 4.1-3 illustrates the major assemblies of the Laser Ranging experiment. Table 4.1-4 is a list of operations that would be performed to set up, calibrate, operate and stow this experiment. Table 4.1-5 is a list of the engineering measurements the operator would monitor. Reference Payload 2, Appendix C, has 11 separate experiments. Utilizing 30 measurements as the average complexity level for each experiment, then about 330 measurements would be the estimate that the Spacelab CDMS must handle. Assuming that each measurement is sampled once per second, and that in normal operation, only one or two experiments are active concurrently, the support requirement is on the order of 60 measurements per second.

This number is smaller than the estimate of 736 measurements for the Spacelab subsystems. Even if all experiments were monitored continuously (330 measurements), they would still be comparable. Therefore, we can conclude that the Spacelab CDMS computer can support the operations of both Spacelab subsystems and Spacelab experiments integration checkout requirements, and still have about 98 percent of its capability available for other purposes.

DMS Memory Compatibility

The analyses of the support systems and experiment system operations requirements indicated that the CDMS computer had more than sufficient capacity, in terms of measurement/command/control rates, to support ground test and checkout activities. However, another facet of computer capacity that must be evaluated is the quantity of main memory space provided versus required. The baseline definition used in the study was that the CDMS computer had a 32,000 16-bit word capacity.

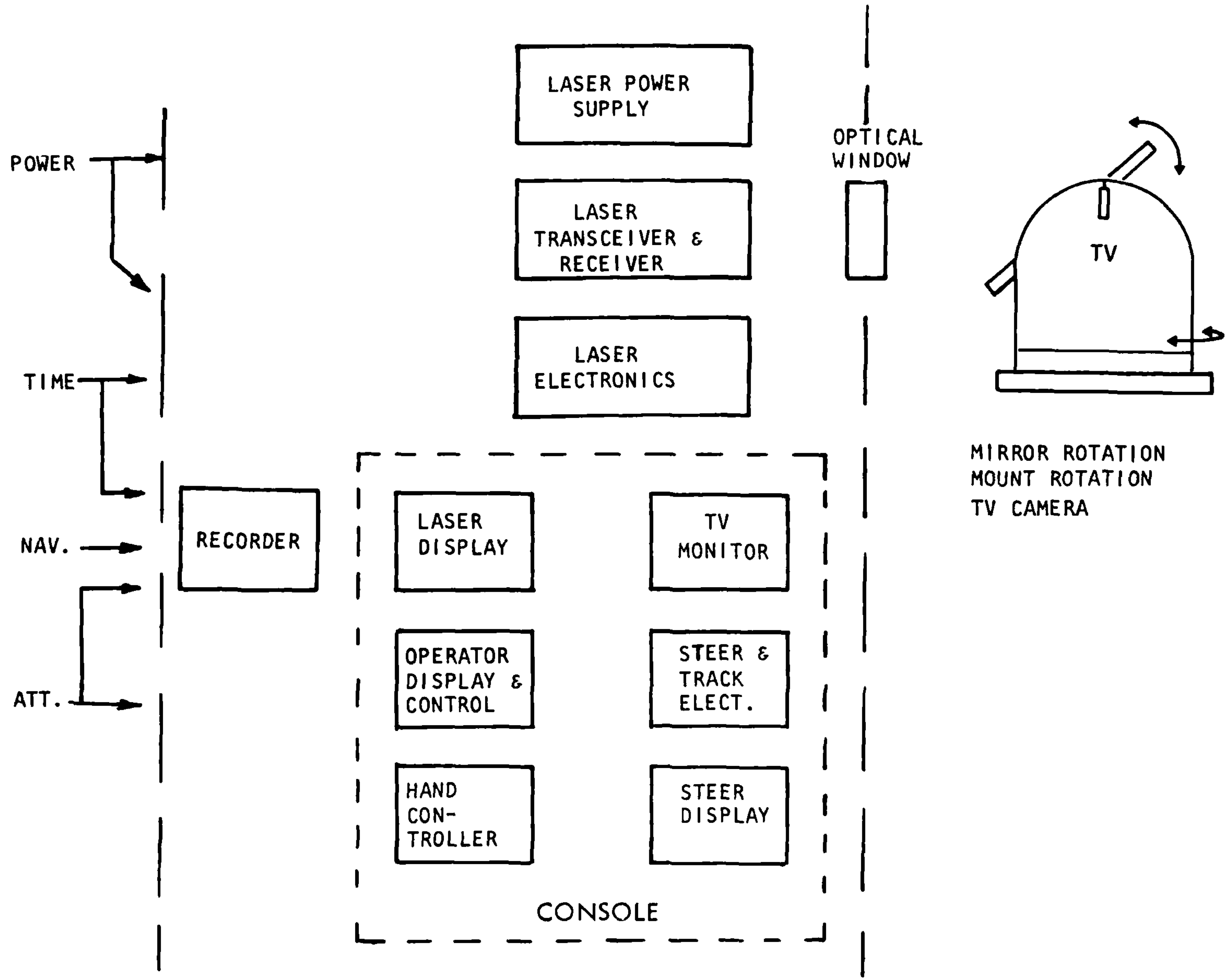

Figure 4.1-3. Laser Ranging Experiment

Table 4.1-4. Laser Ranging - Checkout Operations

Steps	
0	Activate console; verify Orbiter data interface (data, voice, caution/warning)
1	Remove lens cap and window shield
2	Check switch/control list
3	Check recorder tape capacity
4	Energize recorder electronics Verify recorder operation
5	Energize steering electronics and steering display; verify steering operation
6	Energize TV camera and monitor
7	Verify coolant flow rates
8	Energize laser electronics, power supply and display
9	Verify laser operation
10*	Select targets and acquire data a. Enter run identification data
11	Shut down in reverse sequence
12	Secure laser optics
13*	Annotate and stow tape

*Not part of ground operations; on-orbit only.

Table 4.1-5. Engineering Measurement List

MIRROR GIMBAL ANGLE	DEGREES	
MOUNT AZIMUTH ANGLE	DEGREES	
MIRROR GIMBAL DRIVE	ON/OFF	
MIRROR GIMBAL DRIVE	SIGNAL	
MOUNT AZIMUTH DRIVE	ON/OFF	
MOUNT AZIMUTH DRIVE	SIGNAL	
LASER POWER	ON/OFF	
LASER POWER	VOLTAGE	
LASER POWER	CURRENT	
LASER POWER	TEMPERATURE	
LASER TRANSCEIVER	ON/OFF	
LASER TRANSCEIVER	INTENSITY	
LASER TRANSCEIVER	TEMPERATURE	
LASER RECEIVER	ON/OFF	
LASER RECEIVER	SIGNAL	
LASER RECEIVER	SIGNAL	
LASER ELECT	ON/OFF	
LASER ELECT	PULSE RATE	
TIME INTERVAL	SIGNAL	
DEFLECTION	SIGNAL	
IMAGE CONVERTER	ON/OFF	
IMAGE CONVERTER	VOLTAGE	
IMAGE CONVERTER	CURRENT	
IMAGE CONVERTER	TEMPERATURE	
IMAGE INTENSIFIER	ON/OFF	
IMAGE INTENSIFIER	VOLTAGE	
IMAGE INTENSIFIER	CURRENT	
IMAGE INTENSIFIER	TEMPERATURE	
RECORDER DRIVE	ON/OFF	
RECORDER ELECT	ON/OFF	30 MEASUREMENTS
OPERATOR CONTROLS	ON/OFF	
OPERATOR CONTROLS	COMMANDS	30 COMMANDS

As the use of the Spacelab DMS in managing and controlling on-board operations, including checkout, performance monitoring, and configuration control, was not defined at the time of this study, it was assumed that the basic approach of the MSS information management system would be applicable. A data bus and remote acquisition units (RAU), similar to the MSS concept, have been identified as part of the Spacelab CDMS. In essence, the approach is based upon an interactive man-machine relationship. The man interfaces with the data management system through a console that has a multi-function keyboard and one or more multi-function readout displays. This approach is analogous to what is commercially known as an intelligent terminal. In turn, the machine (computer) interfaces with the various subsystems via a digital data bus, both for measurement data acquisition and command interpretations.

The computer has three principal functions: (1) performance monitoring and caution/warning backup, (2) format and control of telemetered data, and (3) command and control. It was assumed in this study that the Spacelab adaptation of the data bus-RAU mechanization to accomplish these functions would be as follows.

Performance Monitoring and Caution/Warning Backup. This function would be automatic, continuous, and standardized for the support module, but variable (for each mission) for the experiments. It is usually constrained to engineering *housekeeping* measurements, some of which go out on the Orbiter telemetry to ground, and is the primary utilization of the digital data bus. Measurements are sorted by function and associated by usage. Each block (or page) is accessible in real time to the crew via the display and keyboard console.

The total of these measurements will probably not exceed 1000 *data points* for any one mission, although the mix will change as different missions are run. One *page* is limited to about 2000 alphanumeric character spaces, plus the formatting instructions. A data point identifies the measurement, its present value, the upper and lower limits of that value, and probably can be expressed in 30 characters, or fifteen 16-bit *words*. Thus, about 15,000 memory words are needed to provide the display function for 1000 data points. Table 4.1-6 summarizes the derivation of the required word total. Figure 4.1-4 illustrates part of a display page. This does not include the instructions necessary to selectively call an RAU and sort the response into the proper memory slot. It can be assumed that most of this function is preprogrammed into the data bus controller, which has its own buffer memory or at least uses a direct memory access channel into the computer memory. About 2000 words should be allotted in the computer operating system to control this data flow.

It can be assumed the display is driven by its own buffer memory, which generates the characters and format. The display is self-regenerating (at 60 frames per second) and updated by the computer once per second.

Table 4.1-6. Page Display Characteristics

ONE DATA POINT PER LINE (30 CHARACTERS, MAXIMUM)
64-CHARACTER ALPHABET (6 BITS PER CHARACTER)
TWO CHARACTERS PER 16-BIT COMPUTER *WORD*
ONE LINE (30 CHARACTERS) EQUALS 15 WORDS
DISPLAY FORMAT ABOUT 2000 CHAR-SPACES, 24 LINES OF 80 CHAR EACH
ONE *PAGE* DISPLAYS 40. DATA POINTS AND REQUIRES 600 WORDS
1000 DATA POINTS EQUALS 25 PAGES AND REQUIRES 15,000 WORDS

EO-5

EQUIPMENT	MEASUREMENT	VALUE	U.L.	L.L.
LASER POWER	AC-V	115	120	110
	AC-A	0.1	0.1	0.1
	TEMP, °C	25	32	14
LASER	PUMP, KV	15	16.5	14.7
	PUMP, MA	200	225	187
	PMT-1 KV	1.5	--	--
	PMT-1 μA	6.0	--	--

Figure 4.1-4. Performance Monitor Display

Telemetered Data. This function is two-fold: It must (1) select and format the digital data to be telemetered and recorded, and (2) select and set up the data paths for analog or wideband telemetry and recording. The first function covers both the *housekeeping* data that are interleaved with the Orbiter (25.6 kbps) telemetry and the experiment data (256 kbps). The *housekeeping* data are selected similar to the displayed *page* (except continuously) and are fed to the Orbiter payload data interleaver. The second function also uses the digital data bus. It does not, however, have to be converted to the display format. This would require about 1000 *words* of memory space, as a buffer, of which about 100 would be the selection and format control overhead.

Command and Control. The payload specialists are directly involved in these functions and utilize the data management system as their communicating tool or mechanism. The computer assists the payload specialists by storing, retrieving, and formatting *pages* of set-up procedures, checkout steps, etc., and translating keyboard depressions into data bus commands to actuators, switches, etc., as illustrated by the *page* in Figure 4.1-5. The library

function is by far the largest consumer of memory space. Recalling that one page requires about 600 computer words, then 100 pages (of text) would use up 60,000 16-bit words. Each page is about 250 English words, about the same as a typewritten page.

EO-5	GMT 00:00:00	MET 00:00:00
SET UP & CALIBRATE		STATUS
1. SW 14 OFF		OFF
2. SW 15 ON		ON
3. LENS CAP		OFF
4. RCDR 3 ON		OFF
5. XMTR 2 ON		OFF

Figure 4.1-5. Command Control Display

Memory Requirements Summary. Summation of the memory requirements indicates:

- Performance monitoring/caution-warning 15,000 words
- Telemetry 1,000 words
- Command/control (100 pages) 60,000 words

A computer main memory of even 64,000 words cannot contain all of this at one time. However, only the performance monitoring (PM) and the telemetry (TLM) are required in residence at all times; only one, two, or three pages of command/control data can be utilized at one time. If the computer memory is extended by a tape recorder (mass memory) with a reasonable access time (3 to 4 seconds), then a very large number of pages can be retrieved without saturating the computer main memory.

The allocation of the SM computer memory is indicated on Figure 4.1-6. A total of 16,000 32-bit words is currently allotted to applications programs for SM support system and experiment control and monitoring. The estimated requirement for normal operation of the SM is 7.5 K words. An additional 8.5 K words are available for growth. These data are based upon a generalized analysis conducted by MSFC on the Phase B definition of the Spacelab (*Spacelab Sortie Payload Software Sizing Analysis*, MSFC, February 1974). The three baseline ATL payloads used in this study were analyzed to establish their memory requirements and, in all three cases, less than 5 K words were required. It should be noted that the requirements reflected on this figure are for the memory to conduct operations. Sensor data processing/resolution is an additional requirement.

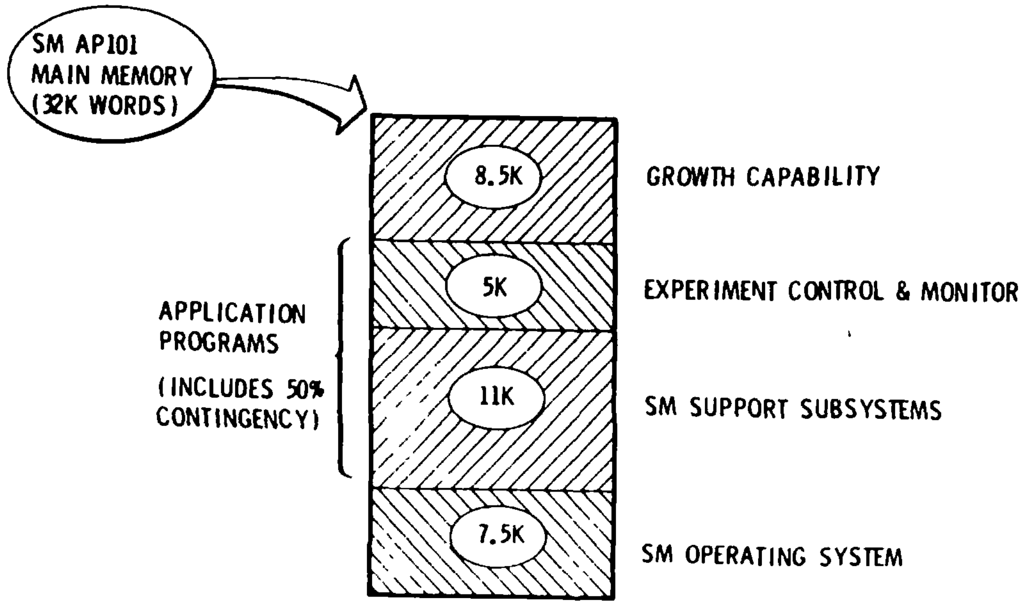

Figure 4.1-6. ATL Flight Operations Software Sizing

Checkout Compatibility

The evaluation of the capability of the CDMS to accommodate operations and memory requirements indicated that the preferred approach of using the CDMS during checkout was feasible. But, for the CDMS to be used in this manner it must be verified as an instrumentation system prior to conducting tests on other equipment. An assessment of the impact on the test and operations sequence was conducted. Ground rules were established to define the status of the CDMS at the initiation of testing. Although the SM is used as the example in the ground rules, these rules are equally applicable to an SM simulator. For example, the post-test revalidation of a simulator is comparable to the post-flight refurbishment of an SM. The ground rules are as follows.

1. The checkout is not for a *first time* operation, but an *Nth-time* cycle. The implication of this rule is that a large part of the SM module will remain intact; only parts that have reported failures are expended or will not be used on the next mission and are removed. What remains need not be reverified component-by-component.

2. The CDMS will be used for Spacelab support system verification. The CDMS performs this function for the entire Spacelab during the mission, and should be able to perform the same function for ground operations. It can readily be conceived as another terminal of the launch processing system; of the concept verification systems; or any other ground simulation, test, and recording system.

3. The SM support systems, and the CDMS in particular, will not be completely disassembled, checked, and then reassembled. This ground rule eliminates a common source of malfunction--the

accidental breakage of cables, wires and connectors. It also eliminates a large amount of time that would be needed to reverify the instrumentation system.

4. Refurbishment and modification shall be on a *remove-and-replace* basis. The actual repair, test and certification of components and subassemblies is a bench operation, is considered to be off-line, and is not part of the SM test and checkout operations flow.

5. Only those components that have been replaced, or added, are checked out at the module level; the remainder are verified by normal operation. This ground rule follows No. 1, in that most of the SM elements have demonstrated their capability and integrity on the previous missions, which is excellent evidence that all the parts are working properly, and working together.

Based upon these ground rules, an estimate was made of the serial time that would be required to utilize the CDMS during checkout. Two types of activities were assessed: (1) initiation of checkout, and (2) status verification.

Initiation of Checkout. These activities relate to the verification/certification that the SM (or SM simulator) is operational and can support the checkout of experiment equipment and/or Orbiter interfaces in the test configuration. It is assumed that the basic operational capability of the SM (in a *stand-alone* state) was demonstrated previously. The steps and time estimates are as follows.

STEP 1. COMPUTER SELF-TEST. This is a standard program stored in the mass memory, complete with test problems, error checks and diagnostics. The computer, keyboard and displays, and tape recorder are needed. Estimated time for verification is 10 minutes (assume no fault).

STEP 2. INSTRUMENTATION SELF-TEST. This is another standard program that exercises the data bus and RAU's by sequentially interrogating each one for a *status check*. The status check is a built-in test function in the RAU. Estimated time for verification is 2 minutes.

STEP 3. COMMAND/CONTROL VERIFICATION. The computer is loaded with programs that interpret manual keyboard and hand-controller functions, and any special display format functions. The operator then commands, via his controls, selected operations which are simulated, and the results displayed for his evaluation. Estimated time for verification is 2 to 3 hours.

STEP 4. PERIPHERAL EQUIPMENT VERIFICATION. These are additional programs to exercise data recorders, printers, plotters, etc. These are test signals--that is, simulated data that are inserted to verify the correct operation. Estimated time for verification is 1 hour.

STEP 5. AUXILIARY EQUIPMENT VERIFICATION. These are manual (not computer) actions to verify the CCTV operation, the film equipment, etc., like a check list. Estimated time is 1 hour.

STEP 6. ORBITER UMBILICAL VERIFICATION. Certain signals (caution/warning, voice, data) will cross the interface via an umbilical; the Orbiter would be simulated by GSE. This is primarily a wiring check where the operator selects a wiring path, injects a stimulus, and observes a response. Estimated time is 2 hours.

In the worst case, the initialization of a test configuration would be less than one work day.

Status Verification. Only three steps are required prior to commencing daily test activities. Two of the three steps are the same as the initialization steps. The steps are as follows.

STEP 1. COMPUTER SELF-TEST. Same as initial verification.

STEP 2. INSTRUMENTATION SELF-TEST. Same as initial verification.

STEP 3. EXPERIMENT DISPLAYS AND CONTROLS VERIFICATION. The experiment-unique displays and controls are presumed to be hardwired to the rack/pallet-mounted experiment equipments. As the experiment equipments are the items undergoing integration/checkout, the status will be varying throughout the test sequence. A manual status check must be accomplished prior to commencement of daily operations. The CDMS can be utilized to provide the reference data *page* for status check. Estimated time for verification is dependent upon the equipment undergoing checkout; CDMS time is negligible.

Summary of Checkout Compatibility. Evaluation of the impact of the preferred checkout approach on the serial time of tests and operations indicates that not only is the approach compatible but will facilitate the checkout process. Even if the worst case were assumed, test configuration initialization within eight hours is a significant improvement over manual approaches. Similarly, daily status determination is accomplished in minimum time.

Evaluation of SM Simulator Usage

The definition of the preferred checkout approach included the use of an SM simulator during Level III integration. In order to assess the impact of including an SM simulator on the checkout sequence, it was necessary to determine the effects on total serial processing time of the flight hardware and the required complement of flight hardware to support the anticipated Spacelab traffic model.

Checkout Sequence Without Simulator

Processing times based upon the nominal period required for the complete Spacelab concept were used in the analysis. A single-shift/five-day work week was assumed. Figure 4.1-7 illustrates the time that each flight hardware

element [support module (SM), racks/pallet (R/P)] would be involved if a simulator were not used. The first bar is the five weeks required for experiment installation and checkout. During this period, only the R/P is required. The shaded bar is 21 weeks long. During this period of time Spacelab integration, Orbiter-cargo integration, launch, mission, post-landing, and SM-R/P refurbishment operations occur. The SM is involved for the entire 21-week period. (It should be noted that there are variations of up to 1.5 weeks in this 21-week period because of differences in shipment requirements between concepts.) The launch is shown to be five weeks prior to the completion of the shaded bar. The activities in those five weeks consist of:

Weeks	
1	Mission
2	Post-mission operations including Spacelab shipment
2	SM, rack/pallet refurbishment

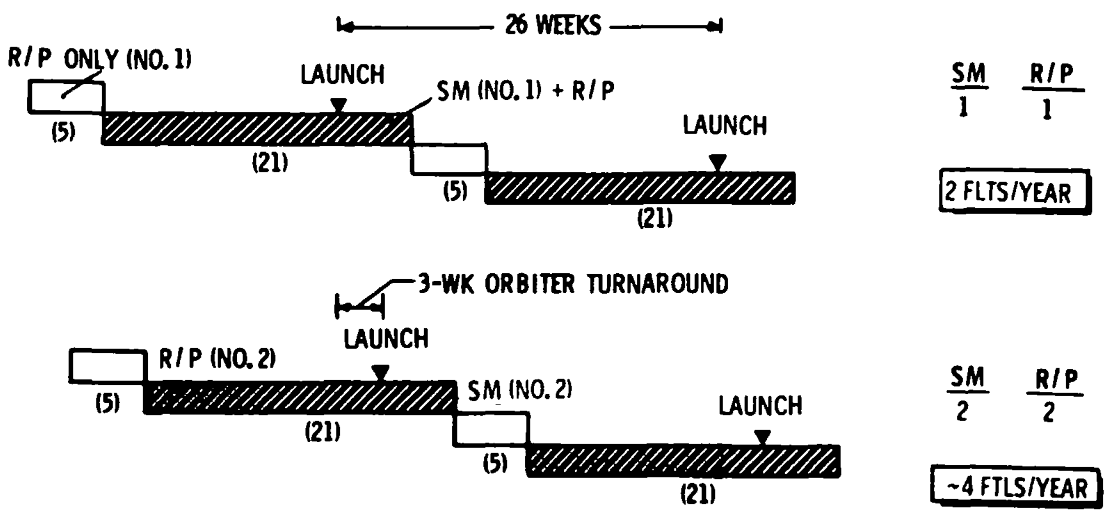

Figure 4.1-7. Checkout Sequences Without Simulator

The 21-week period was shaded to illustrate that during this period, the SM and the rack/pallet are both required in the operations as contrasted to the 5-week period of experiment installation during which only the rack/pallet assembly is required. Thus, the Spacelab has a 26-week processing cycle that results in one SM and one R/P being able to support a flight rate of two flights per year. If a flight rate of four flights per year were required, then an additional R/P and SM would be needed. If desired, the processing cycle of the second Spacelab could be staggered so that the time between flights could vary anywhere from 3 to 13 weeks. The lower limit is defined by the 3-week turnaround time for the Orbiter.

Checkout Sequence With Simulator

Figure 4.1-8 is similar to 4.1-7 with the exception of the introduction of a simulator in the checkout sequence. The effect of the simulator is that it reduces the serial processing time of the SM from 21 weeks to 12 weeks. Based

on the flows illustrated, one simulator with one SM and two R/P's can support a flight rate of four flights per year. This combination of equipment has the following processing cycles:

Weeks	
2	Simulator
12	Support module
26	Racks/pallet

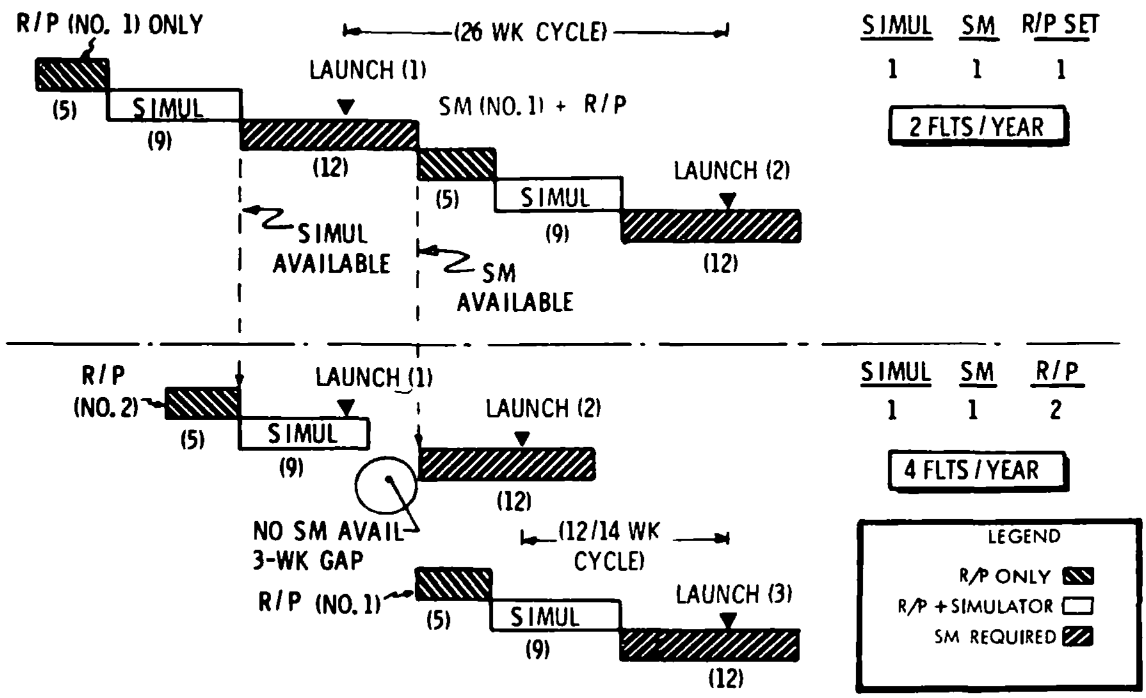

Figure 4.1-8. Checkout Sequences With Simulator

Comparison of Approaches

Based upon the involvement times of the equipment in Figures 4.1-7 and 4.1-8, the required complement to support various flight rates for the two approaches was determined. Figure 4.1-9 summarizes the flight-rate sensitivity for the two approaches. For a Spacelab program that envisions a flight rate of one or two flights per year, the choice of using a simulator during checkout is concept-dependent. While the use of the SM in this situation has the obvious plus of saving the delta cost of an SM simulator, the utilization of the SM is not maximum. In Concept I, the IC was the owner of the SM and was defined as a centralized activity for the support of multiple Spacelab users. Maximum utilization of the SM is required. Similarly, in Concepts II, III, and IV the launch site is the SM owner and also would support multiple users with maximum utilization of the SM. In Concept V, the user owns the SM and if only two flights per year are planned, the use of a simulator is questionable. One SM would support the operation; there is no apparent justification for the delta capital investment for an SM simulator.

•WITH SIMULATOR

	SIMUL	SM	EM/P
PROCESSING CYCLE (WEEKS)	9	12	26
MAX CYCLES PER YEAR (ONE ITEM)	~6	4.3	2.0

•SM ONLY

	SM	EM/P
PROCESSING CYCLE (WEEKS)	21	26
MAX CYCLES PER YEAR (ONE ITEM)	2.4	2.0

ANNUAL FLIGHT RATE	ELEMENTS REQUIRED				
	WITHOUT SIMULATOR		WITH SIMULATOR		
	SM	R/P	SIM	SM	R/P
1	1	1	1	1	1
2	1	1	1	1	1
3	2	2	1	1	2
4	2	2	1	1	2
5	3	3	1	2	3
6	3	3	1	2	3
7	3	4	2	2	4
8	4	4	2	2	4
9	4	5	2	3	5
10	5	5	2	3	5
11	5	6	2	3	6
12	6	6	2	3	6
13	6	7	3	3	7
14	6	7	3	4	7
15	8	8	3	4	8

Figure 4.1-9. Spacelab Modules and Simulator Complement Vs. Flight Rate

At flight rates greater than two per year, there are cases when the simulator approach requires one additional item of equipment (flight rates of 7, 9, 14). But the additional item is always a simulator. In these cases, the non-simulator approach would be preferred if the simulator costs were greater than one-half the cost of an SM. But, with proper design and selection of equipment, it is believed that an SM simulator should cost less than one-fourth the cost of an SM. In addition, the simulator approach avoids the schedule risk of near-continuous use of the SM and maximizes the utilization of the single most costly item in the Spacelab program, the SM. Even in Concept V, the use of a simulator is recommended at flight rates of two or less per year. With the simulator, a user that owns an SM can share the use, and thus the costs, of an SM.

CHECKOUT REQUIREMENTS

Three categories of checkout requirements were evaluated: functional, environmental, and operational. The preferred checkout approach emphasized the demonstration/verification of planned flight operations. The functional checkout requirements must reflect not only this approach, but also the buildup of the assembly levels and the potential interactions between the payload and the Spacelab/Orbiter. Environmental test requirements should reflect the potential interactions of an integrated payload. It was assumed that the individual experiment equipments, Spacelab, and Orbiter would be certified to operate in the anticipated environments. Hardware processing techniques (operations) could impose unique test and/or installation requirements and directly impact the sequence of activities. The ground operations should reflect a logical buildup sequence and minimization of repeat testing.

Functional Checkout Requirements

As the Spacelab/Orbiter were considered to be operational and the integrated payload was mission-unique, two different sets of functional test requirements were identified.

Spacelab/Orbiter

During the operational era of the Spacelab/Orbiter the capabilities, limits, and constraints of these two program elements will have been well-established. Systems performance characteristics, maintenance schedules, trend data, and refurbishment schedules will have been derived based upon developmental and operational flights. Also, crew safety provisions and procedures will have been verified. The goal is to reach an operational status comparable to a commercial airline.

One additional characteristic of the Spacelab/Orbiter concept is the establishment of a *line-replaceable-unit* level that precludes detailed on-line testing of subsystems. That is, only interfaces between major subassemblies need to be verified. If a subassembly malfunctions, the entire unit is replaced; on-line troubleshooting within a subassembly is not planned.

These planned characteristics of the Spacelab/Orbiter program elements preclude the detailed testing at each level of assembly that was required on past space programs. Because the Spacelab/Orbiter are reused many times, only a revalidation of the functional operations is required. A complete teardown/buildup of equipments is not required. End-to-end tests of subsystems are adequate unless a subassembly has been replaced based upon mission operation, trend data, or maintenance schedules. The test sequences presented subsequently in this volume reflect only the functional reverification of Spacelab/Orbiter systems with allowances for periodic maintenance of equipments.

In general, Spacelab/Orbiter interfaces also are repetitive from flight to flight. The performance characteristics of the interfaces will have been established. Therefore, during Level II integration, Spacelab/Orbiter interface compatibility demonstrations will be minimal. During Level I integration, interface verification tests are primarily to verify workmanship/integrity

of interconnections. The subsequently developed test sequences reflect the standardization and repetition of Spacelab/Orbiter interfaces. (Orbiter/payload interfaces are mission-unique and will require detailed compatibility evaluations.)

Experiment Systems

In order to establish the integration and checkout requirements associated with experiment systems, the pre-integration status of the experiment equipments must be defined. Throughout the development of the integration and checkout process, emphasis has been placed upon the retention of experiment equipment ownership/cognizance by the PI's. This ownership/cognizance includes establishment and verification of the performance capability and constraints of the individual experiment equipments. This verification must be accomplished prior to introduction of the equipments into the payload integration process. Operational interface verification or functional operation in the installed configuration is the primary test task of the integration and checkout process.

The Spacelab/Shuttle offer a unique space platform-launch vehicle. In previous space programs, almost the entire spacecraft-launch vehicle was crew-safety related. During the Spacelab/Shuttle operational era, crew safety provisions will be provided by these two elements. The experiment systems/payload must be designed for safe operations but need not include specific crew safety equipment.

The close-couple between safety and reliability of previous space programs can become two separate functions with Spacelab payloads. Repetitive testing of payload equipment to establish a high degree of confidence/assurance of the adequacy of crew safety provisions is not required. Because experiment equipments are not part of the crew safety provisions, multiple equipment paths and high degrees of redundancy are not required. Reliability and quality assurance of experiment equipments is the responsibility of the PI's--not the payload integrator or Spacelab/Shuttle operator. Repetitive testing at the various assembly levels will not be required.

Safety will still be a stringent requirement for all payload equipment. Provisions must be included for the protection of personnel and equipment during all phases of both ground and flight operations. In some cases, these provisions must be demonstrated during checkout. For example, payload sensors that must be extended beyond the Orbiter mold line must include jettison provisions as well as normal retraction capability.

To ensure the safety of operations, a group of qualified personnel should be planned to conduct payload safety evaluations. The group would work directly with the PI's as well as the payload integrators. The specific tasks that this group would perform are as follows:

1. Prepare guidelines and criteria for safety, possibly assembled from existing safety manuals and provided to cover hazardous materials and procedures. These guidelines and criteria would be used by the PI's to understand and avoid potential hazards and to preclude the requirement for safety demonstration tests.

2. Conduct hazard analyses, in conjunction with the PI's, of proposed and existing experiment equipment designs, test procedures, and operational procedures. A systematic analytical study of each experiment system could eliminate potential hazards and simplify the test activities.

3. Develop a review/approval, *go/no-go* procedure for all materials, designs, and procedures. This approach will establish confidence in the safety of experiment systems and minimize demonstration test requirements.

All of the safety group tasks have two objectives: safe operations, and minimization of testing. The test and operations sequences developed subsequently in this volume reflect the use of a safety group in minimizing/definitizing safety-related tests during Spacelab-payload and Orbiter-cargo hardware integration.

The assumed status of experiment systems at the initiation of payload integration negates testing and retesting of experiment equipments as the levels of assembly progress. Testing of equipment after each hardware transfer/major move to gain assurance that equipment validity was maintained is not necessary in a continuing program. Standardized/controlled moves with predictable environments would be established. The short mission times, known flight environments, and familiarity with the constraints of near-earth space operations, coupled with the disassociation of experiment equipments and crew safety provisions, permit a de-emphasis on multi-level testing.

Composite Requirements

Figure 4.1-10 summarizes the functional checkout requirements for an Orbiter/Spacelab/payload. Functional operation in all operating environments of the Spacelab, Orbiter, and individual experiment systems has been verified prior to initiation of integration and checkout activities. Only functional reverification and operational interface verification is required of the Spacelab/Orbiter. Functional checkout of experiment systems in the installed/integrated configuration is required as well as functional verification of interfaces between experiment systems and Spacelab/Orbiter systems.

Every retest expends programmatic resources. Also, schedules become more critical as the level of assembly increases. In particular, as the level of integration approaches the launch configuration there is insufficient time to repeat previously verified operations. Therefore, the functional test philosophy adopted in this study was that once an integrated operation in the flight configuration (at any level of assembly) has been verified, that verification will not be repeated. Only interfaces will be verified at subsequent assembly levels. For example, the only operations that must be verified after Spacelab integration (Level II) are the interfaces that result from the interconnection of the Orbiter with the Spacelab/payload. Spacelab interfaces with the payload would not be reverified during Level I integration. The checkout sequences presented subsequently in this volume reflect this functional checkout philosophy.

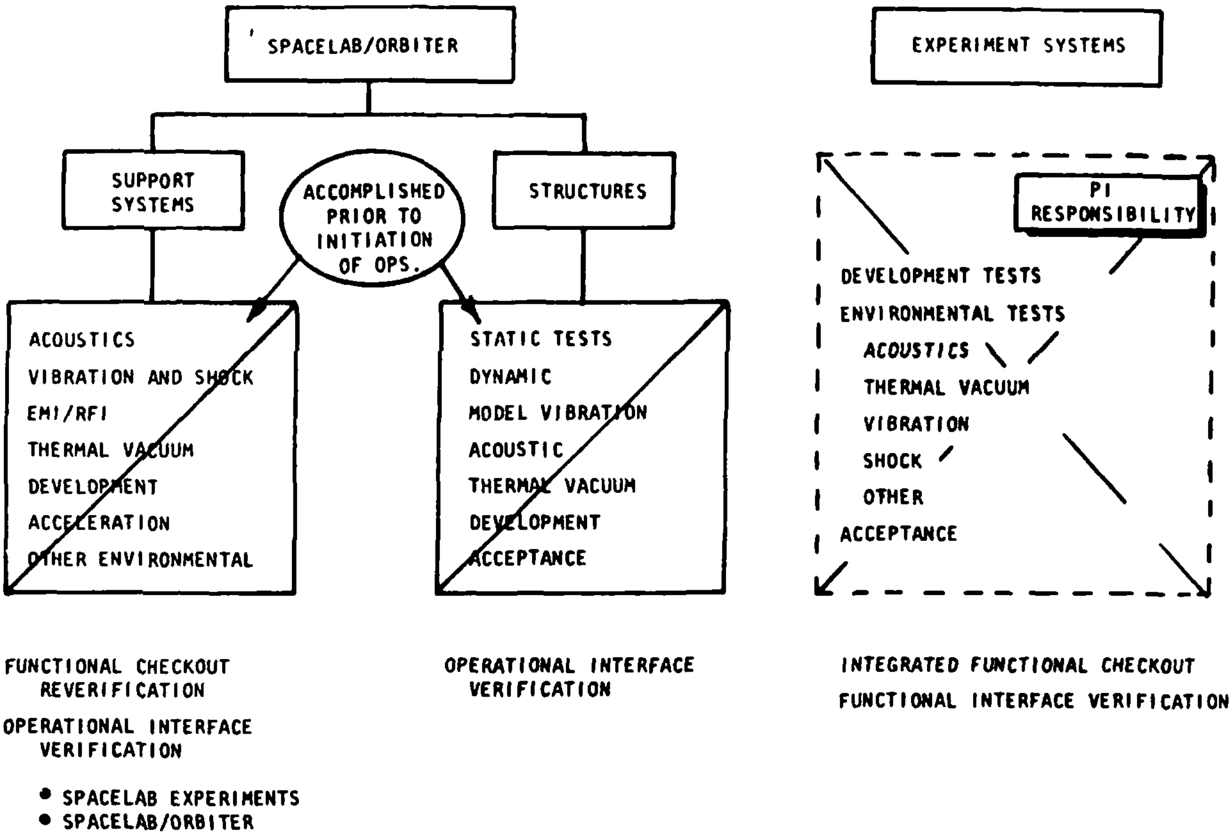

Figure 4.1-10. Program Potential Test Matrix

Environmental Checkout Requirements

The various environments that experiment systems will be exposed to during hardware processing are as follows:

- Acceleration
- Shock
- Vibration (structurally induced)
- Acoustic vibration
- Vacuum
- Thermal
- RFI/EMI
- Humidity, dust, and corrosive atmosphere

Table 4.1-7 indicates the ground and/or flight operations that will impose the various environments and which operations will impose the maximum environmental stress. From past space programs, experience has shown that acceptable methods of verification of equipment compatibility with anticipated environments are: (1) similarity (with hardware previously flown or tested), (2) analysis, (3) simulation tests (tests of simulated hardware), and (4) test of mission hardware. The environmental compatibility verification/certification activities of several previous space programs were evaluated to determine an applicable and preferred approach for Spacelab payloads.

Table 4.1-7 Experiment Environments

Operation	Thermal	Vacuum	Shock	Acceleration	Vibration	Acoustic	Humidity, Dust, Corrosion Atmos	EMI	RFI
Experiment Development/ Acceptance	Ambient	--	Handling	--	--	--	Indoor	GSE test equipment	--
Ship to integration facility (1)	--	--	Transport*	--	Transport	--	Outdoor*	--	--
Experiment integration (Level III)	--	--	Handling	--	--	--	Indoor	Other expmt GSE*	Other experiments
Transport (to Level II integration site)	--	--	Transport	--	Transport	--	Outdoor*	--	--
Spacelab integration	--	--	Handling	--	--	--	Indoor	Spacelab, expmt, GSE*	--
Transport	--	--	Transport	--	Transport	--	Outdoor*	--	--
Orbiter/Cargo Integration (Level I)	--	--	--	--	--	--	Indoor	Orbiter, Spacelab, Experiment *	--
Prelaunch operations	--	--	Move to pad	--	Move to pad	--	Shuttle payload bay	--	--
Launch and boost to orbit	Orbiter payload bay	Sea level to space vac	Booster engines	Boost X-axis*	Rocket engine and aero vibration*	Rocket engine and aero loads *	Orbiter payload bay	--	--
Orbital operations	Solar and deep space*	Space vacuum *	--	--	--	--	--	Orbiter, Spacelab, Experiment*	Orbiter, other expmts
Deorbit and entry	Orbiter payload bay	Space vac. to sea level	OMS engines	Deorbit X-Y axes	OMS engine & aero vib	Aero loads	Orbiter payload bay	--	--
Landing	--	--	Landing *	Braking	--	--	Orbiter payload bay	--	--
Transport (to Level III integration site)	--	--	Transport	--	Transport	--	Orbiter	--	--

*Maximum stress.

(1) Individual experiments--commercial carrier

Previous Space Programs

The following paragraphs discuss several orbital and airborne experiment programs that were evaluated to provide insight into practices employed for verifying payload compatibility with the carrier vehicle and mission environments before commitment to the mission. Both manned and unmanned space programs were considered.

Apollo "J" Missions. These missions comprised three lunar landing flights: Apollo 15, Apollo 16, and Apollo 17. On these missions, a number of scientific experiment payloads were installed in the Scientific Instrument Module (SIM) bay (Sector IV) of the Service Module. This sector was cleared of Command and Service Module (CSM) subsystem hardware and was enclosed by a door which served as structure during launch and boost, and which was jettisoned by pyros just prior to lunar orbit injection to expose the experiments to space.

Experiment hardware was qualified for the J-missions by functional and environmental testing to specified levels during development. Apollo electromagnetic compatibility (EMC) requirements were included. The actual flight hardware underwent acceptance testing to predicted flight environment levels.

The Service Module SIM bay was qualified by vibration testing of Apollo Spacecraft 105 (SC105), with simulated experiment masses, in the acoustic vibration chamber at JSC. Thermal-vacuum qualification tests were performed on the thermal-vacuum test article, SC-2TV2 (with SIM bay), and experiment test hardware in Environmental Chamber A at JSC.

Verification of experiment hardware flight readiness for the three J-missions was based on acceptance tests (to flight levels) and by similarity to qualification test hardware.

Functional compatibility of experiment hardware, including EMC, was verified by checkout tests after installation in the SIM bay. Experiments were installed while at the MSOB, except for some late experiments which were installed at the launch pad. This delayed complete functional experiment verification to checkout at the launch pad (with some increased risk to the experiment program) and precluded environmental testing of the integrated flight payload.

In summary, J-mission experiment hardware underwent qualification testing during development. Functional compatibility with the vehicle was verified by checkout testing after installation, and environmental compatibility was verified for the first mission by the acoustic vibration chamber test and the thermal-vacuum chamber test described above. Environmental compatibility for the second and third missions was based on similarity with the first mission.

Skylab Program. This program included experiment and module configurations with significant analogies to the Shuttle/Spacelab program. The booster used was the two-stage Saturn launch vehicle, consisting of the S-IC and S-II stages. The Skylab configuration consisted of five major elements, four of which were enclosed in a payload shroud during boost. The major elements were

a multiple docking adapter (MDA), which provided the docking interface with the CSM and supported the majority of the earth resources experiments; an airlock module (AM), which provided an airlock to space and controls for operational systems; an Apollo telescope mount (ATM), containing a large telescope and six solar experiment sensors; an orbital workshop (OWS), containing crew quarters and experiment facilities; a Saturn V instrument unit (IU), used only during launch and initial deployment; and a payload shroud (PS), used during boost to orbit. The ATM provides a good analog with pallet-mounted experiments, while experiments in the OWS, MDA, and CSM contained experiments analogous to those in the Spacelab experiment module.

The various Skylab modules were environmentally verified by analysis, test, and similarity. Environmental tests were not conducted on the complete Skylab configuration,which was verified by analysis.

The OWS (an S-IVB structure) underwent vibration testing in the acoustic-vibration test facility at JSC. The vibration test article consisted of the OWS structure and furnishings with mass simulated subsystems and experiments. Thermal-vacuum testing was performed on the refrigeration and waste management subsystems in the environmental chamber at McDonnell-Douglas, Huntington Beach, California, and on a single panel of the solar arrays in a TRW environmental chamber. Experiments in the OWS underwent environmental qualification and acceptance tests during development.

The AM and MDA modules were assembled and underwent manned thermal-vacuum chamber tests at McDonnell-Douglas, St. Louis, Missouri. Acoustic-vibration tests were performed with a vibration test article similar to the flight article.

The ATM was assembled together with the telescopes and sensors, and vibration-tested as a complete package in the MSFC vibration test facility. It was then shipped to JSC for a 28-day therma-vacuum test in a JSC environmental chamber. While vibration and acceleration loads measured during boost were in agreement with analytically predicted values (frequency within 10 percent, and steady-state and dynamic accelerations within 1.5 percent), a telescope pointing problem occurred during orbital operations. Instability in the telescope pointing control system was associated with structural vibration modes induced by crew exercise activity and attendant vehicle attitude control maneuvers. Vigorous crew activity during exercise exceeded that defined in the crew activity model, and induced vibrations at the ATM beyond the rate capability of the attitude pointing control system. The operational fix consisted of limiting crew activity and vehicle maneuvers when taking data.

The payload shroud underwent pyrotechnic separation tests in a vacuum chamber at Langley. It was verified for the acoustic-vibration environment by similarity with a shroud used on a comparable USAF program.

The Skylab carried 60 items of experiment hardware in the various modules, as shown in the following tabulation.

MODULE	NO. OF EXPERIMENT HARDWARE ITEMS
ORBITAL WORKSHOP (OWS)	45
MULTIPLE DOCKING ADAPTER (MDA)	4
APOLLO TELESCOPE MOUNT (ATM)	9
COMMAND & SERVICE MODULE (CSM)	2
TOTAL	60

Experiment hardware was required to demonstrate functional and environmental capability by qualification and acceptance tests performed by the responsible experimenters. Most of the flight hardware was located in the OWS. Experiment hardware (not necessarily the final flight hardware) was installed, and functional tests were performed at McDonnell-Douglas, Huntington Beach, California. This hardware was removed for shipment of the OWS to KSC. Some equipment was modified or replaced before shipment to KSC, where it was all re-installed in the OWS and functional integrated checkout testing was performed on the complete Skylab in the protected environment of the VAB. Only limited testing and servicing was accomplished at the launch pad.

Electromagnetic compatibility requirements were imposed on all experiments and Skylab subsystems, and verified by qualification test and acceptance tests. Electromagnetic compatibility was monitored at each stage of integration and checkout prior to launch.

P72-2 Spacecraft. This spacecraft program carries and provides functional support for four experimental payloads. It is launched on an Atlas rocket booster and placed in circular orbit by a solid propellant rocket motor (apogee insertion motor).

During the development phase of the program, a modal vibration test was performed on the spacecraft structure with mass simulated subsystem hardware and experiments to verify and modify the dynamic analysis model. This test provided sinusoidal excitation at selected input points to determine natural frequencies, general response profile, and damping characteristics. The modal test was supplemented by testing in an acoustic chamber at Rockwell Los Angeles Division, where the suspended spacecraft and simulated payloads were subjected to acoustic environment at 6 dB below and at full predicted flight environments. These tests were conducted early enough to permit structural design changes (e.g., bulkhead stiffeners).

As a part of the Phase III integrated test, the final P72-2 spacecraft, complete with subsystem hardware and payloads (except for a simulated apogee insertion motor), underwent acceptance testing in a TRW acoustic chamber at 3 dB below and at full predicted flight levels. Measured vibration levels on components were within the levels predicted.

A performance test of thermal insulating techniques used to minimize parasitic heat transfer to the RM-20B* payload radiator was conducted during the

*Experiment designation used on the P72-2 Spacecraft program.

development phase. The test was conducted on a radiator with structural interface and heat shield in a Space Division environmental chamber with -320 F (LN_2) cold walls and 10^{-6} torr vacuum.

Later, during the integrated systems test, the complete P72-2 Spacecraft with actual subsystem hardware and payloads (except apogee insertion motor and squibs) underwent thermal-vacuum testing in an environmental chamber at McDonnell-Douglas, Huntington Beach, California, to demonstrate the spacecraft capability to maintain the temperature-critical components and interfaces within specified limits during all critical mission phases. Measured temperatures were within analytically predicted limits.

EMI requirements for susceptibility and emission were specified for subsystems and experiments. The EMI characteristics of individual equipments was established during acceptance testing. EMI was emperically evaluated at each level of integration. Both hardware and specification changes/waivers were required.

CV-990 Airborne Research Program. The NASA-Ames Airborne Science Office (ASO) has conducted a program of airborne flight tests for selected experiments since 1965, using a Convair 990 jet aircraft (CV-990) as the carrier. Flights are scheduled locally and worldwide for conducting astronomical and earth-viewing experiments at flight altitudes to 15 km. Single astronomy experiment payloads have also been flown in Learjet and Lockheed C-141 aircraft.

A major objective of this program is to reduce cost and enhance research accomplishment by full experimenter involvement and responsibility. This is achieved by placing full responsibility for the performance and reliability of the experiment upon the experimenter. ASO requires only that the experiments satisfy flight safety requirements. This involves a design safety review of drawings, photographs or sketches, plus stress calculations of the experiment installation. The hardware installation is inspected by aircraft inspectors. Any experiment testing is at the discretion of the experimenter, and documentation of test results is not required by ASO.

ASO provides an *experimenter's handbook* outlining capabilities of the CV-990 and the experiment support available, including power and data recording capabilities. Experiment construction requirements and safety standards are also included.

It should be noted, however, that all experiments actually undergo flight environmental testing in the mission preparation process. After experiment installation in the aircraft, a pilot check flight is conducted with only ASO personnel on board. Following this flight, one or more initial operational shakedown flights are made with the experimenters aboard. The data producing mission flights are then conducted.

Experiment compatibility with the aircraft electrical and avionics systems, as well as interfaces and interference with other experiments, is checked during pre-flight checkout and on the operational shakedown flights. Final verification with the automated digital data acquisition system (ADDAS) is conducted on the shakedown flight.

The ASO program flights from 8 April to November 1972 were reviewed to assess applicability of the approach to Shuttle-Spacelab operations. This review included five CV-990 missions involving 62 experiments and 76 experimenters, plus 17 Learjet missions with 17 experiments and 50 experimenters. The CV-990 missions typically carried 5 to 15 experiments for up to 10 flights, over a period of 4 to 6 weeks. Learjet missions carried one astronomy experiment per mission for 4 flights over a period of 1 to 2 weeks. Of the experiments conducted during this period, only 5 percent resulted in complete data loss due to malfunctions, while 68 percent experienced no malfunctions. Twelve percent had malfunctions which were repaired in flight with no data loss, and 15 percent had malfunctions with some data loss. Thus, 80 percent of the experiments had no data loss at all, 15 percent had partial data loss, and only 5 percent experienced total data loss.

Advanced Applications Flight Experiments (AAFE). AAFE is a Langley Research Center program that utilizes a C-54 aircraft for airborne research. The experimenter is required to submit a plan for reliability and quality control, including formal acceptance testing for review. Experiment functional and environmental test data are submitted to Langley for flight acceptance. For example, in the microwave radiometer experiment, the environments tested include vibration, shock temperature, and altitude. These tests were conducted at Space Division laboratories in Downey, California.

This program is similar to the Ames CV-990 program in that the airplane is operated by Langley with the experimenter being responsible for experiment operation. Several experiments can be accommodated on a single flight, necessitating experiment integration by Langley. Functional compatibility is verified by pre-flight checkout tests.

Scout Program. This program involved launching a single experiment payload on a Scout rocket. Functional and environmental qualification and acceptance tests were required for flight acceptance. The payloads were tested for all applicable environments, including spinup. The flight hardware, in final form, was acceptance-tested to mission-predicted environments. Functional compatibility was verified by checkout tests during integration and before launch.

Summary of Previous Program Trends. It is apparent from a review of single-mission programs (e.g., P72-2, Scount, Skylab), that confidence in payload capability is directly related to an accurate definition of the operating environments. Uncertainty in the definition of the environment requires the inclusion of margins in the design definition. In addition, first-time payload equipment requires extensive testing to develop the confidence required to commit this equipment to flight.

In multiple-mission programs, these uncertainties also apply to first flights. However as the program progresses, experience in previous flights permits accurate redefinition of the environments, and experience with payload hardware provides verification (and modification) of math models to establish higher confidence levels.

This trend (see Figure 4.1-11) is apparent in the repetition of the Apollo J-missions, where initial full-scale environmental testing of the SIM bay with simulated or actual experiments preceded the first flight, and where the second and third missions were verified for flight by analysis and similarity. In the Skylab program, emphasis on full-scale testing was maintained for new equipment (experiments and subsystems) while capability of the OWS (S-IV) and Apollo CM were accepted by similarity.

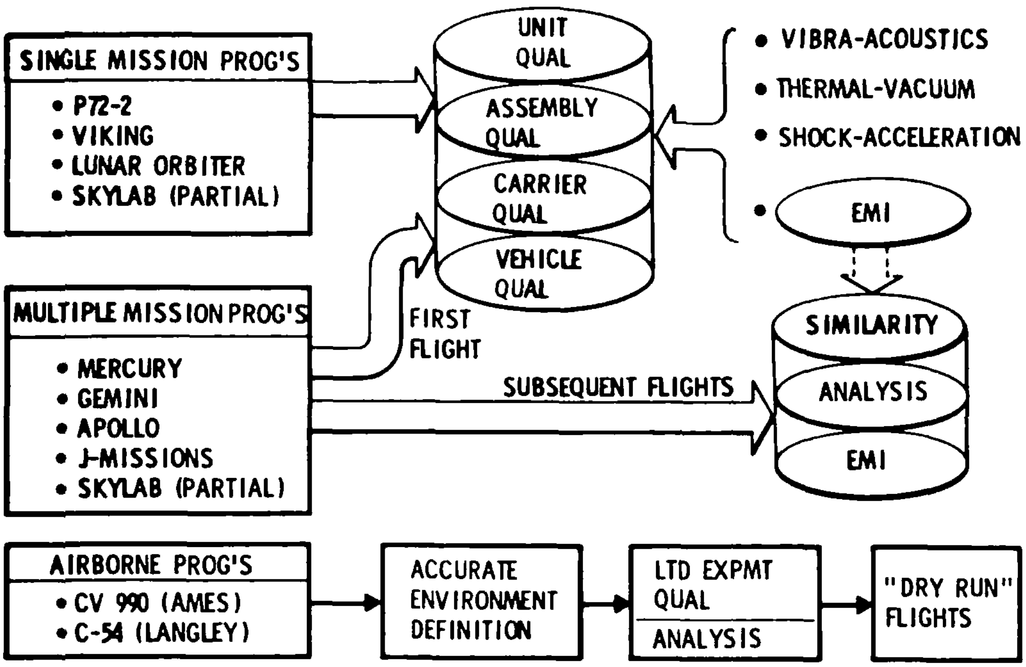

Figure 4.1-11. Trend in Environmental Test Requirements

The informality of full-scale payload testing in the CV-990 and AAFE programs is especially marked. Here, the flight vehicle characteristics and environments imposed on experiments were accurately known, and NASA experience with flying a variety of payloads made verification by analysis or similarity acceptable.

A major exception to the deletion of tests for multiple-mission programs was EMI testing. While susceptibility and output interference limits were specified for experiment equipment, potential interaction with other experiments or with the carrier vehicle cannot be predicted with confidence. Under pressure of schedules, EMI requirements are sometimes compromised or waived, and interaction with new equipment as payload integration progresses is not always predictable. While specific measurements of EMI may be performed on individual equipment items, EMC is normally verified by functional testing designed to surface EMI effects at each stage of integration.

ATL Spacelab Program Environmental Verification Techniques

Environmental testing of the complete Spacelab and the pallet-only configurations will be required for qualification/acceptance testing of the initial Spacelab flights, and may be required for subsequent Spacelab/experiment configurations that are very unique. It is reasonable to assume that in an on-going program such as the ATL/Spacelab/Orbiter, the carriers would have been qualified because of the existence of adequate available facilities (not including any European capability). Available environmental chambers, capable of the thermal-vacuum testing of the full-scale complete Spacelab and pallet-only configurations, are listed in Table 4.1-8. The table lists four major thermal-vacuum test chambers, including a description of their present capabilities. The payload test requirements are listed in the lower portion of the table. It should be noted that in all cases, each facility has sufficient capability to satisfy the payload requirements. Similarly, the acoustic-vibration test facilities, capable of testing the complete Spacelab and pallet-only configurations, are listed in Table 4.1-9.

Since the payload carriers (Spacelab/Orbiter) would have been qualified and each individual experiment would have completed a separate environmental verification test program, the analysis of the integrated payload-carrier interactions is the remaining issue. The following two subsections establish the basic assumptions concerning the Spacelab and experiment hardware elements preceding integration, and the environments that the hardware will encounter. The final subsection describes the selected environmental verification approach.

Assumptions. The basic assumptions on the environmental verification status of the Shuttle, Spacelab, and individual experiments are as follows.

1. Shuttle and Spacelab modules have been qualified by analysis, test, and flight to specified performance and environments.

2. Spacelab-Shuttle functional compatibility has been demonstrated by ground tests and previous flights.

3. Spacelab compatibility with mission environments has been demonstrated on previous flights.

4. Experiment hardware has been designed and tested to meet Shuttle/Spacelab program requirements for functional interfaces and mission environments.

   While these two programs do not specifically require formal qualification tests for payload hardware, it is strongly recommended that experiment hardware be tested during its development to demonstrate compatibility with significant mission environments, as defined by the two programs, for the following reasons:

   a. Any incompatibility of the experiment hardware with the mission environment can be discovered in time to make corrections prior to entering the Spacelab ground

Table 4.1-8. Thermal Vacuum Test Chambers

	ORGANIZATION LOCATION FACILITY NAME	ENVIRONMENTS SIMULATED	CHAMBER DIMENSIONS (FT)	MINIMUM TEMPERATURE (°C)	MINIMUM WORK PRESSURE (TORR)
EXISTING TEST FACILITIES		PRESENT CAPABILITIES			
	AEDC ARNOLD AF STA (TENN) AEROSPACE ENV CHAMBER (MK 1)	SPACE SIMULA. SOLAR SIMULA. (0-143 W/FT^2)	42D x 82 H (34D x 65.5H, WORK SPACE; 20D DOOR)	LN_2 WALLS	5×10^{-9}
	NASA-JSC HOUSTON, TEXAS SPACE ENV SIM. LAB	SPACE SIMULA. SOLAR SIMULA. (6 FT D, 130 W/FT^2)	65D x 65 H (40 D, DOOR)	-185	1×10^{-6}
	BOEING COMPANY SEATTLE, WASH (KENT) SPACE ENV. LAB	SPACE SIMULA. SOLAR SIMULA. (20 FT D; 130 W/FT^2)	39 D x 50 H (28 D x 40 H, WORK SPACE)	LN_2 SHROUDS (H_e PANEL, -253)	1×10^{-7} (ULT. 1×10^{-9})
	GENERAL ELECTRIC CO. PHILADELPHIA, PA. (VALLEY FORGE) SOLAR THERMAL VACUUM CHAMBER	SPACE SIMULA. SOLAR SIMULA. (14 FT D; 140 W/FT^2)	32 D x 54 H (21 D, SPECI-MEN)	-179	1×10^{-9}
		PAYLOAD TEST REQUIREMENTS			
		SPACE SIMULA.	15 D x 60 (MAX)	-100 DEEP SPACE DIRECT SOLAR	1×10^{-6}

Table 4.1-9. Acoustic-Vibration Facilities

ORGANIZATION LOCATION FACILITY NAME	FACILITY TYPE	CHAMBER VOLUME (FT^3) & INSIDE DIAMETER (FT)	MAX SOUND PRESS. LEVEL (dB)	FREQUENCY RANGE (Hz)	ACOUSTIC POWER (WATTS)	GENERATOR TYPE
EXISTING TEST FACILITIES	PRESENT CAPABILITIES					
AFF DL WRIGHT-PATTERSON AFB, OHIO SONIC FATIGUE FACILITY	PROGRESSIVE WAVE OR REVERBERANT	154,000 70 x 56 x 42 H	174 (PROG. WAVE) 162 (REVERB)	50 - 10K	1000K 1000 Hz	PURE-TONE SIRENS
NASA-JSC HOUSTON, TEXAS SPACECRAFT ACOUSTIC LAB	PROGRESSIVE WAVE PROGRESSIVE WAVE REVERBERANT OR FULL REVERB.	441,000 60 x 70 x 105H	169 (PROG. WAVE) 153 (REVERB)	20 - 20K	100K	AIR MODULATORS
LTV DALLAS, TEXAS ACOUSTIC LAB	REVERBERANT	70,000 (915 x 15 ACCESS)	148	50 - 10K	20K	ELECTRO-PNEUMATIC (BREADBOARD OR SINE)
LOCKHEED MISSILE & SPACE SUNNYVALE, CALIFORNIA LARGE VEHICLE ACOUSTIC TEST FACILITY	REVERBERANT	189,000 44 x 50 x 86 H	156	40 - 10K	240K	LING EPT 200 AIR MODULATORS, WYLE WAS-3000 TRANSDUCERS
WYLE LABS HUNTSVILLE, ALABAMA ACOUSTIC TEST FACILITIES	REVERBERANT	100,000 40 x 50 x 60 H	155	FULL PWR 25 - 600 TO 10K @ REDUCED POWER	120K	AIR MODULATORS WYLE WAS-3000
	PAYLOAD TEST REQUIREMENTS					
	--	PAYLOAD 15 D x 60 H MAXIMUM	145	31.5 - 8K	--	--

processing cycle. Delays will affect only the experiments concerned, and would not penalize other experiments or the timely progress of the Spacelab integration process.

b. Experiment characteristics, when exposed to mission environments (e.g., vibration), will be useful in analysis of the characteristics of the integrated Spacelab and experiments. Data from experiment environmental tests can be combined with data from Spacelab module tests and previous Shuttle flights to provide a firm base for verifying compatibility of the complete payload by analysis and similarity with previously flown missions.

c. Individual experiments can be tested in smaller, more accessible, and less costly facilities than the complete Spacelab payload.

ATL/Spacelab Environments. The following paragraphs describe the environments to which the integrated Spacelab will be subjected. Also included are the primary areas of concern during the major test/processing cycle when these environmental effects are encountered, and the method proposed to assure that the integrated experiment complement is compatible with the anticipated environmental level.

Shock and Acceleration. The shock and acceleration loads that the experiment equipment will encounter during ground handling through launch and on-orbit operations are nominal. Proper shock mounting can be provided to safeguard the equipment during these operational phases. However, a structural integrity stress analysis will be required to verify that the experiments can withstand the crash loads, which are significant. It is understood that the experiments will not be expected to operate following their being subjected to crash loads, but they will be required to maintain their structural integrity and present no hazards. It must be established that the experiment equipment undergoing a crash will have the proper structural provisions to prevent breakup of the equipment, and thereby eliminate the possibility that the experiment equipment could jeopardize crew safety or the integrity of the Orbiter.

Vibration-Acoustic. Vibration analysis will be required for each Spacelab payload because mass distribution will vary from mission to mission. This is especially true for the pallet-mounted payloads. It is assumed that modal vibration and acoustic tests will be conducted during Spacelab development with a variety of payload configurations. This will serve to verify/modify the math model and further refinements will be made after the first flights, leading to a high-confidence math model for operational Spacelab missions.

Should a pallet-experiment configuration develop that is not adequately covered by the math model, it is proposed that a pallet with experiment-simulated masses be tested in an acoustic test facility to verify the natural frequencies and damping characteristics of the payload. Conducting these tests as soon as the proposed configuration is developed will provide sufficient time to permit the redesign or modification to structural supports, if the test results indicate that it is necessary. Sufficient advanced notification will enable the integrator to complete the interface hardware modifications prior to initiation of experiment integration.

Thermal. Two principal thermal environments to which the Spacelab will be exposed are (1) enclosed Orbiter payload bay during launch and boost to orbit (experiments not operating in a stowed configuration), and (2) Orbiter operations on orbit with the payload doors open (experiments deployed and operating).

During the launch boost period, heat will be transferred by radiation, conduction and convection and will involve interaction among the experiments, Spacelab modules, and Orbiter structure as well as the active thermal control systems.

During orbital operations, experiments mounted on the pallet will be operating in a vacuum environment; heat transfer by radiation to deep space and from the sun or earth must be evaluated. The Spacelab active thermal control system can provide cooling by means of coldplates. Air circulation in the SM/EM includes ducting in the equipment racks. Considerable experience has been acquired on heat transfer characteristics in the space environment, and it is assumed that the Spacelab modules and individual experiments will have undergone thermal analysis and thermal environmental testing to the defined mission environments during development. With these data available, together with thermal data from previous flights, it will be possible to verify the capability of the integrated experiment equipments to perform in the mission thermal environment by analysis. Data from previous flights will be especially significant because direct examination of the experiment hardware upon return from the space environment can be accomplished with the Spacelab/Orbiter sortie mission mode of operations.

Final verification of the capability of the Orbiter-Spacelab to maintain required thermal control of experiments in the Spacelab modules or the experiment equipment canisters, where sea-level ambient pressure and nominal temperatures are maintained, will be demonstrated by functional testing during experiment integration, Spacelab integration, and Orbiter-cargo integration. Similarly, verification of the active thermal control system interfaces with coldplate-mounted equipment will be verified during the functional tests of those three integration levels.

Vacuum. Experiments mounted on the pallet in the Orbiter payload bay will be exposed to space vacuum environment during the orbital portion of the mission. It is assumed that all pallet-mounted experiment hardware will be tested for operation in this environment during development. It is also assumed that the Spacelab modules will be tested in a thermal/vacuum chamber during development, so that a leak test during Spacelab integration will provide adequate verification of compatibility with the space vacuum environment.

Electromagnetic Interference. Electromagnetic interference (EMI) emission and susceptibility limits are established by the Orbiter/Spacelab programs for all electrical/electronic equipment, including payloads. It is assumed that the carrier systems and individual experiments will demonstrate compliance with these requirements by testing during development. The Orbiter/Spacelab programs require a 6-dB margin between interference and susceptibility levels for each function for electromagnetic compatibility.

It is neither practical nor necessary to conduct quantitative EMI testing throughout the hardware integration process. Individual experiment systems would have been evaluated for internal EMI effects; therefore, only integrated operations need be evaluated for EMC. In general, the primary source of EMI is power switching transients. All anticipated combined operations, including power switching, should be evaluated for EMC during checkout. Effective verification of EMC can be achieved by noting the effects of integrated operations on individual experiment response to commands and data during experiment integration, Spacelab integration and, finally, Orbiter-cargo integration. This requires that functional testing be designed to monitor significant functions while exercising all switching functions in the integrated experiment configuration, with additional interfaces becoming involved at successive phases of the ground processing cycle.

Humidity, Dust, and Corrosive Atmosphere. This environment should not present a problem during the experiment integration processing cycle because:

- Experiment installation, integration, and checkout activities with the Spacelab will be conducted in a controlled laboratory environment during the various phases of ground processing, and flight hardware will be protected from adverse ambient environments during shipping.
- Spacelab installation in the Orbiter payload bay, and integration verification tests, will be conducted in the controlled atmosphere of the Orbiter Maintenance Facility after which the payload bay will be closed.
- The Orbiter payload bay will be supplied with filtered, conditioned air or dry N_2 gas during the remainder of prelaunch, launch, and boost operations.

Verification Approach. The various environments to which the integrated ATL/Spacelab will be exposed during a mission were identified previously. Verification of ATL/Spacelab compatibility with mission environments can be accomplished by several methods and at various stages of development and the ground processing cycle. Verification methods considered include the following:

- Similarity with previously flown or tested hardware and payload configurations.
- Analysis, using a math model verified by test or previous flights.
- Testing a similar configuration.
- Testing the actual flight hardware configuration.

Verification of environmental compatibility is considered at the various program phases from development to Orbiter-cargo integration. But, in previous programs, the trend was (see Figure 4.1-11) to utilize at least a first-flight (assembly qual/carrier qual/vehicle qual) qualification of the integrated experiment/carrier interface. In multiple-flight programs, until the environment was adequately defined, vibra-acoustics, thermal-vacuum and shock-acceleration compatibilities were established by empirical testing. EMC required repetitive testing in addition to similarity analyses.

In contrast to previous programs, examination of the Shuttle/Spacelab development program indicates that the environment definition will be accurately defined. Math models will be updated based upon both qualification tests and actual flight data (see Figure 4.1-12). Initial Spacelab flights may require some integrated environmental testing. Simulated experiment equipment could be used for these tests; however, in the steady-state ATL program, no integrated environmental testing (other than EMI) is recommended.

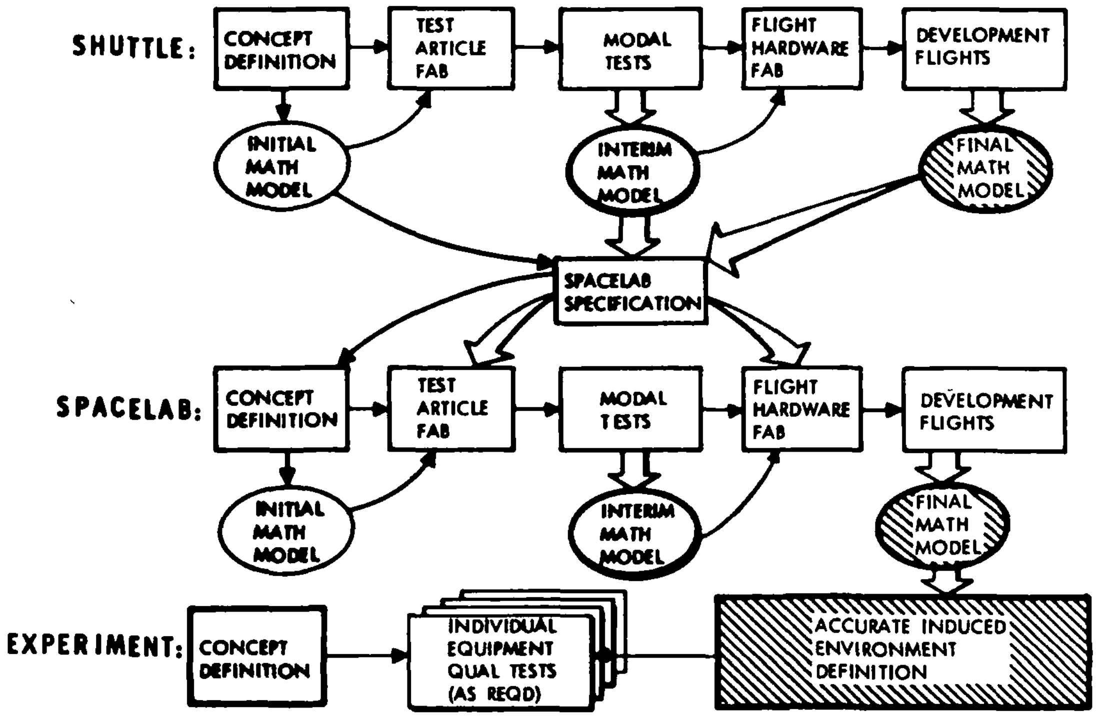

Figure 4.1-12. ATL-Induced Environment Definition

It is recommended that, as far as the integrated payload is concerned, environmental qualification be accomplished by analysis or similarity, and the individual experiment equipments be selected or designed to operate within the defined environment.

As mentioned previously, EMI testing during the integration cycle is the only environmental test recommended. The current technology is inadequate to control or predict the potential interference/interaction of equipments. The recommended ATL experiments environmental verification testing is summarized in Table 4.1-10.

The test and operations sequences described reflect inclusion of only EMI testing during integration. Manpower estimates, including documentation requirements and responsibility assignments, that are described subsequently reflect the systems analysis effort required to specifically and uniquely define the other environments for each mission.

Table 4.1-10. ATL In-Process Requirements Summary

	INDIVIDUAL EXPERIMENTS	INTEGRATED PAYLOAD	COMMENTS
VIBRA-ACOUSTICS	TEST	ANALYSIS	INTEGRATED ANALYSIS WITH MATH MODEL
THERMO-VACUUM	TEST	ANALYSIS	INTEGRATED ANALYSIS WITH THERMO PROFILE MODEL
SHOCK-ACCEL	TEST/ANALYSIS	ANALYSIS	FLIGHT SAFETY REQUIRES STRESS ANALYSIS
			GROUND TRANSPORT IS PRIMARY CONCERN
RFI/EMI	TEST/ANALYSIS	TEST	INTEGRATED EMI ENVIRONMENT NOT ACCURATELY PREDICTABLE

Specification of the environments and system analysis of the integrated configurations are the primary activities that the payload integrator should conduct in direct support of experiment equipment development. Individual equipment qualification test results should be coordinated with the payload integrator.

Operational Test Requirements

The processing of flight hardware could influence test/retest requirements as well as installation/assembly procedures. The working environment (clean room) was evaluated to determine that a reasonable sequence of the buildup operations was provided. The analysis was made to determine whether any of the assembly or test/integration operations would be delayed to a later/higher assembly level by cleanliness requirements. Shipping/transportation was also evaluated because the adopted technique could also result in significant retest.

Impact of Cleanliness Constraints

Cleanliness requirements could cause the installation of experiment equipment to be out of sequence with respect to the appropriate assembly level. That is, if only an air-conditioned environment were available during Level III integration, some experiment installation and checkout may have to be postponed until a later assembly level (possibly Level I integration). This delay would be very disruptive to the optimum test schedules and hardware flows. Delaying the installation of experiments from Level III integration to Level I may have the impact of invalidating some of the previously established interfaces and result in additional resource expenditures and schedule extension for retest. Installation of experiment equipment on the pallet segments may be severely constrained after Level III integration has been completed. Center-of-gravity constraints and, thus, equipment-mounting provisions, may dictate a specific assembly sequence. Therefore, a consistent cleanliness capability should be maintained throughout the processing cycle.

It is anticipated that during the operational period of the Spacelab, numerous payloads will require a 100,000 class clean room environment. Some sensors will require even more stringent clean room environments. As it is impractical to maintain the Orbiter cargo bay at levels more stringent than 100,000 class, this level was baselined for all hardware processing facilities. It should be noted that the ATL experiments of the three baseline

payloads used in this study could be processed in a standard air-conditioned environment. But the more stringent 100,000 cleanliness level was imposed to reflect the general applicability of the processing concepts. Thus, 100,000 class environment must be maintained during Levels III and II activities. The planned Orbiter Processing Facility at KSC that will be used for Level I integration includes 100,000 class provisions. During preparations for transportation, bagged enclosures for experiments, airlocks and special transportation canisters (scrubbed down after each use) will be utilized to meet the required cleanliness level. Shipping time estimates include these precautionary measures.

Impact of Shipping/Transportation

Because of the size of the various levels of assembly, the method selected for shipping/transportation was significant. If previously verified connections were broken to facilitate the shipment of Spacelab hardware elements, then re-verification after shipment would be required. Alternate techniques were investigated for the shipment of both modular and assembled configurations. Figure 4.1-13 represents the various combinations of hardware and transportation modes. Barge or ship transportation is costly, time-consuming, and has limited utility; i.e., for land-locked sites, alternate modes are necessary. In the case of the ATL, this method could be used; however, when other potential Spacelab users are considered (e.g., Ames, European), the time and costs become excessive. For these reasons, barge/ship transportation modes for any combination of hardware was rejected as being unrealistic.

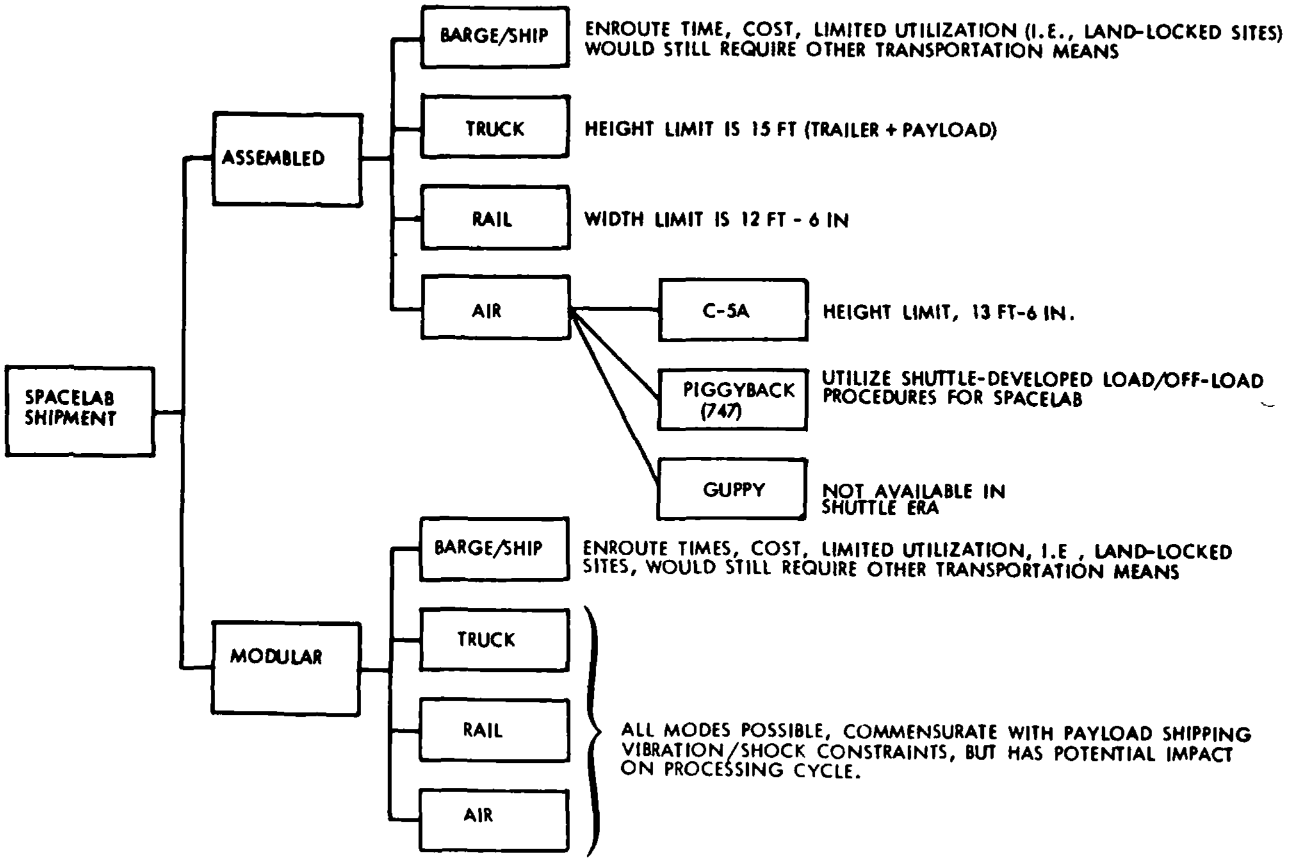

Figure 4.1-13. Spacelab Transportation Trades

Any assembled combination of the support module, experiment module and/or pallet precludes both rail or truck transportation modes because the present diameter of the modules is 13 feet, 7 inches, which makes the assembled or single-element dimensional characteristics exceed both rail and highway restrictions.

Thus, the remaining option open for transporting the assembled Spacelab --air transportation--is the only practical method. Referring to Figure 4.1-13, it is noted that the *Guppy* is not a prime candidate due to its non-availability. The Shuttle program has established the feasibility of using a 747-type aircraft for a piggyback shipment approach for the Orbiter. Therefore, the 747 piggyback approach is the recommended transportation mode for the assembled Spacelab. Pallet-only Spacelabs could be shipped in the C-5A aircraft if the combined height of the pallet and pallet-mounted sensors is less than 13.5 feet.

Modular shipment of Spacelab elements is feasible since their length of 10 feet could be accommodated by rail, truck, or air (C-5A) by proper orientation and positioning during loading operations. It should be recognized that the ground transportation mode selected should be reviewed for compatibility with the vibration/shock constraints of the equipment being shipped. Also, modular shipment implies breaking interfaces between equipment items previously tested, which may result in stringent retest requirements with potential impact on processing cycle time.

Figure 4.1-14 presents the modular Spacelab transportation trade from two points of view: post-flight shipment and pre-flight shipment.

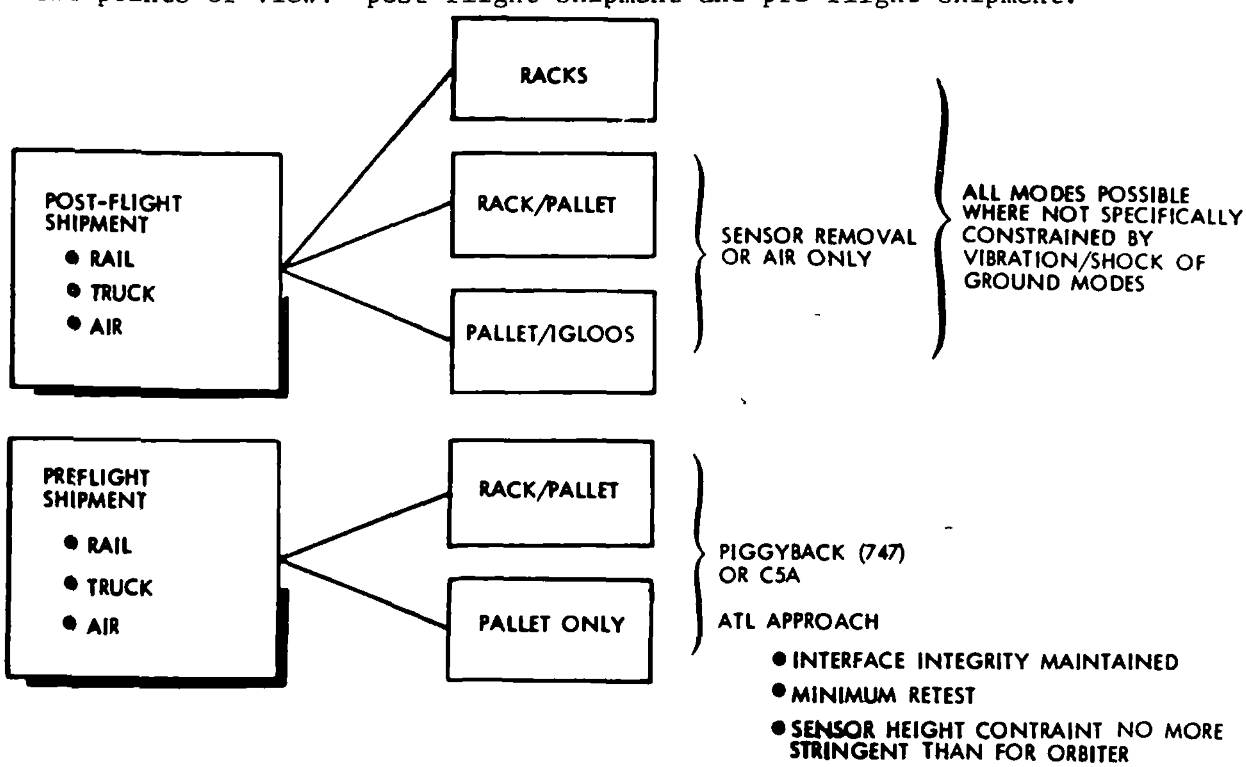

Figure 4.1-14. Modular Spacelab Shipment

During post-flight operations, the integrity of the interfaces are of less concern; disassembly operations of the racks, rack/pallet, and pallet/igloo elements can be accomplished at the launch site. With sensor removal from the pallets at the launch site, all transportation modes are possible including the C-5A for air transport. However, removal of the sensors is not recommended because of the potential requirement for special-handling GSE, increased packaging requirements, and increased processing time.

Pre-flight shipment of integrated rack/pallet or pallet-only module configurations should be accomplished only by air transportation. Limiting the height of pallet-mounted sensors, for ground transportation reasons, to values less than those imposed by the Orbiter is not acceptable. Therefore, the use of the 747 piggyback is the baseline approach for purposes of general applicability.

It is recognized that the rack/floor sets will fit into the C-5A, and numerous integrated pallets will be less than the C-5A height constraint of 13.5 feet. ESRO/ERNO has identified a special GSE item that permits the tilting of the end bulkhead of the SM or EM to an overall height of less than 13.5 feet. Thus, rack/pallet interfaces that are connected through the end bulkhead and have been verified during Level III integration can be maintained during shipment. In those cases where combined pallet-sensor height is less than 13.5 feet, the use of the C-5A as the transport aircraft is practical.

Composite Requirements Matrix

The test and operations requirements for the processing of Spacelab payloads were developed through an iterative *top-down* and *bottom-up* approach. Rudimentary, skeletonal timelines of the major anticipated tests were established first (*top down*). As the preferred checkout approach and test philosophy were developed, the major tests and associated subordinate tests were detailed. After all identifiable tests and operations were define, a summation to an integrated flow level was accomplished (*bottom up*). Thus, the test and operations sequences were developed concurrently with the test requirements.

A composite set of the test and checkout requirements (TCR) for the processing of the complete Spacelab is presented in Table 4.1-11. A similar listing of the requirements for the pallet-only configuration is presented in Table 4.1-12. Both pre-flight and post-flight test activities are defined for levels of integration/disassembly/refurbishment. These TCR listings reflect the following guidelines, assumptions, and processing optimizations.

- Developmental, environmental, and performance capability tests of Orbiter, Spacelab, and individual experiment systems were conducted prior to the initiation of the integration and checkout of payload flight hardware.
- Level IV integration, individual experiment system acceptance testing, is accomplished prior to receipt of experiment equipments at the payload integration site. This integration may occur with the experiment equipments mounted in flight racks if a dedicated rack/rack set is feasible. However, as dedicated rack/rack sets are not always available for a single

Table 4.1-11. Complete Spacelab TCR Matrix

LINE ITEM	INTEGRATION LEVEL I	II	III	TEST/CHECKOUT REQUIREMENT
1			X	VERIFY PLUGS-OUT CONTINUITY OF RACKS/EXPERIMENTS/EQUIPMENT
2			X	LEAK-CHECK FLUID CONNECTIONS AT AFT BULKHEAD & PALLET INTERFACES
3			X	VERIFY SM I/F SIMULATOR MECH/ELECT CONNECTIONS WITH FACILITY
4			X	VERIFY SM I/F SIMULATOR/RACKS/PALLET INTERFACES
5			X	VERIFY SERV UNIT FLOW & CONTROL TO RACK/PALLET COOLANT LOOPS
6			X	PERFORM BUS ISOLATION TESTS OF RACKS/EXPERIMENTS/PALLET
7			X	PERFORM ELECTRICAL POWER DISTRIBUTION TEST
8			X	VERIFY CAUTION/WARNING CIRCUITRY
9			X	PERFORM COMPUTER & INSTRUMENTATION SYSTEMS SELF-CHECKS
10			X	VERIFY DMS COMMAND & CONTROL & PERIPHERAL EQUIPMENT
11			X	VERIFY GROUND DATA BASE (GDB) COMPATIBILITY VIA GDB UMBILICAL
12			X	VERIFY RACKS/EXPERIMENT AUXILIARY EQUIPMENT--CCTV, INTERCOM, ETC
13			X	VERIFY READINESS OF EXPERIMENT OR SUPPORT EQUIPMENT FOR ACTIVATION
14			X	ACTIVATE CONTROL & DISPLAYS & SUPPORT EQUIPMENT
15			X	VERIFY PERFORMANCE OF C/D CONSOLE DURING EXPERIMENT FUNCTIONAL CHECKOUT
16			X	VERIFY OPERATION OF PALLET-MOUNTED DEPLOYABLE EXPERIMENT EQUIPMENT
17			X	VERIFY OPERATION OF RACK-MOUNTED MECHANICAL EXPERIMENT EQUIPMENT
18			X	VERIFY FUNCTIONAL OPERATION OF EXPERIMENTS/SUPPORT EQUIPMENT
19			X	VERIFY DATA PROCESSING/RECORDING EQUIPMENT DURING EXPERIMENT CHECKOUT
20			X	CONDUCT EMI/RFI TESTS
21		X		CONDUCT SM/EM/PALLET ELECT BONDING CHECKOUTS AFTER COMPLETE SPACELAB ASSEMBLY
22		X		CONDUCT & VERIFY ALL COMPLETE SPACELAB ELECTRICAL/MECHANICAL INTERFACES
23		X		SERVICE & VERIFY COOLANT FLOW THROUGH GSE
24		X		VERIFY ORBITER INTERFACE SIMULATOR OPERATIONAL CAPABILITY
25		X		PERFORM COMPLETE SPACELAB BUS ISOLATION TEST
26		X		CONDUCT COMPLETE SPACELAB ELECTRICAL POWER DISTRIBUTION TESTS
27		X		VERIFY COMPLETE SPACELAB CAUTION/WARNING CIRCUITRY
28		X		CONDUCT COMPLETE SPACELAB COMPUTER SELF-CHECKS
29		X		VERIFY COMPLETE SPACELAB DMS COMMAND/CONTROL & PERIPHERAL EQUIPMENT
30		X		VERIFY COMPLETE SPACELAB AUXILIARY EQUIPMENT--CCTV, INTERCOM, LIGHTING, ETC
31		X		CHECK OUT SIGNAL DISTRIBUTION VIA SM-ORBITER UMBILICAL
32		X		VERIFY GDB OPERATION VIA GDB UMBILICAL
33		X		CONDUCT FUNCTIONAL C/O OF COMPLETE SPACELAB SUPPORT SYS/EXPMT EQUIP INTERFACES
34		X		CONDUCT EMISSIVITY TESTS OF COMPLETE SPACELAB EXTERIOR SURFACES
35		X		CONDUCT COMPLETE SPACELAB 24-HOUR PRESSURE DECAY LEAK CHECK
36		X		CONDUCT COMPLETE SPACELAB WEIGHT/BALANCE TESTS
37	X			PERFORM COMPLETE SPACELAB/ORBITER PRE-INSTALLATION INTERFACE VERIF TESTS
38	X			SERVICE COMPLETE SPACELAB WITH NON-HAZARDOUS FLUIDS & LOW-PRESSURE GASES
39	X			VERIFY ORBITER READINESS TO ACCEPT COMPLETE SPACELAB
40	X			PERFORM ORBITER/COMPLETE SPACELAB INTERFACE VERIFICATION TESTS
41	X			PERFORM ORBITER INTEGRATED TEST (OIT)
42	X			CONDUCT COMPLETE SPACELAB/ORBITER EMI/RFI TESTS
43	X			PERFORM ABBREVIATED LEAK CHECKS A TUNNEL B TUNNEL HATCH C COMPLETE SPACELAB INTERFACE
44	X			PERFORM ORDNANCE INSTALLATION TESTS
45				CONDUCT COMPLETE SPACELAB FINAL PRELAUNCH TESTS
46				PERFORM COMPLETE SPACELAB HAZARDOUS MATERIALS LOADING TESTS
47			X	REFURBISH RACKS/PALLET A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM B REMOVE RACKS/EXPERIMENTS C REFURBISH RACKS D VERIFY OPERABILITY OF FLUID SYSTEM COMPONENTS
48			X	REFURBISH SUPPORT SYSTEMS AND SM/EM ASSEMBLY A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM B VERIFY OPERABILITY OF FLUID SYSTEM COMPONENTS C VERIFY OPERATION OF DMS COMPONENTS E VERIFY OPERATION OF CPSS (AIRLOCKS, IPS, ETC) AS REQUIRED

Table 4.1-12. Pallet-Only TCR Matrix

LINE ITEM	INTEGRATION LEVEL I	II	III	TEST/CHECKOUT REQUIREMENT
1			X	VERIFY PLUGS-OUT CONTINUITY OF EXPMT IGLOOS/EXPERIMENTS/EQUIPMENT
2			X	LEAK-CHECK FLUID CONNECTIONS AT PALLET/IGLOO/EXPERIMENT INTERFACES
3			X	VERIFY SUPPORT SYSTEMS IGLOO & ORBITER SIM SETS ELECT/MECH CONNECTIONS W/FACILITY
4			X	VERIFY SUBSYSTEMS IGLOO SIM/ORBITER SIM/EXPERIMENT IGLOO/PALLET INTERFACES
5			X	VERIFY SERVICING UNITS FLOW & CONTROL TO PALLET/IGLOO COOLANT LOOPS
6			X	PERFORM BUS ISOLATION TESTS OF PALLET/IGLOO EXPERIMENTS
7			X	PERFORM ELECTRICAL POWER DISTRIBUTION TESTS
8			X	VERIFY CAUTION/WARNING CIRCUITRY
9			X	PERFORM COMPUTER & INSTRUMENTATION SYSTEM SELF-CHECKS
10			X	VERIFY DMS COMMAND/CONTROL & PERIPHERAL EQUIPMENT
11			X	VERIFY PALLET/IGLOO AUXILIARY EQUIPMENT--CCTV, INTERCOM, ETC
12			X	VERIFY GROUND DATA BASE COMPATIBILITY WITH GROUND DATA BASE (GDB) UMBILICAL
13			X	VERIFY READINESS OF EXPERIMENTS & SUPPORT EQUIPMENT FOR ACTIVATION
14			X	ACTIVATE PALLET/IGLOO, CONTROL & DISPLAYS & SUPPORT EQUIPMENT
15			X	VERIFY PERFORMANCE OF C&D CONSOLE DURING EXPERIMENT FUNCTIONAL TESTS
16			X	VERIFY OPERATION OF PALLET-MOUNTED DEPLOYABLE EXPERIMENT EQUIPMENT
17			X	VERIFY OPERATION OF EXPERIMENT/IGLOO MOUNTED MECHANICAL EQUIPMENT
18			X	VERIFY FUNCTIONAL OPERATION OF EXPERIMENTS/SUPPORT EQUIPMENT
19			X	VERIFY DATA PROCESSING/RECORDING EQUIPMENT DURING EXPERIMENT CHECKOUT
20			X	CONDUCT EMI/RFI TESTS
21		X		CONDUCT PALLET/SUBSYSTEMS IGLOO ELECTRICAL BONDING TESTS AFTER P/SS IGLOO MATING
22		X		CONDUCT & VERIFY PALLET/SUBSYSTEMS IGLOO ELECTRICAL/MECHANICAL INTERFACES
23		X		SERVICE & VERIFY COOLANT FLOW THROUGH GSE
24		X		VERIFY ORBITER INTERFACE SIMULATOR OPERATIONAL CAPABILITY
25		X		PERFORM PALLET/SUBSYSTEMS IGLOO BUS ISOLATION TESTS
26		X		CONDUCT PALLET/SUBSYSTEMS IGLOO ELECTRICAL POWER DISTRIBUTION TESTS
27		X		VERIFY PALLET/SUBSYSTEMS IGLOO CAUTION/WARNING CIRCUITRY
28		X		CONDUCT SUBSYSTEMS IGLOO COMPUTER SELF-CHECKS
29		X		VERIFY SUBSYSTEMS IGLOO DMS COMMAND/CONTROL & PERIPHERAL EQUIPMENT
30		X		VERIFY PALLET/SUBSYSTEMS IGLOO AUXILIARY EQUIPMENT--CCTV, INTERCOM, ETC
31		X		VERIFY SIGNAL DISTRIBUTION VIA SUBSYSTEMS IGLOO/ORBITER UMBILICAL
32		X		VERIFY GROUND DATA BASE OPERATION VIA THE GDB UMBILICAL
33		X		CONDUCT FUNCTIONAL CHECKOUT OF IGLOO SUPPORT SYSTEMS/EXPERIMENT EQUIP INTERFACES
34		X		CONDUCT EMISSIVITY TESTS OF PALLET/SUBSYSTEMS IGLOO EXTERNAL SURFACES
35		X		CONDUCT SUBSYSTEMS IGLOO 24-HOUR PRESSURE DECAY LEAK CHECK
36		X		CONDUCT PALLET/SUBSYSTEMS IGLOO WEIGHT/BALANCE TEST
37	X			PERFORM PALLET/IGLOO/ORBITER PRE-INSTALLATION INTERFACE VERIFICATION TESTS
38	X			SERVICE PALLET/IGLOO WITH NON-HAZARDOUS FLUIDS & LOW-PRESSURE GASES
39	X			VERIFY ORBITER READINESS TO ACCEPT PALLET/IGLOO
40	X			PERFORM PALLET/IGLOO/ORBITER INTERFACE VERIFICATION TEST
41	X			PERFORM ORBITER INTEGRATED TEST
42				CONDUCT ORBITER/PALLET/IGLOO EMI/RFI TESTS
43	X			PERFORM ORDNANCE INSTALLATION TESTS
44	X			CONDUCT FINAL PALLET/IGLOO PRE-LAUNCH TESTS
45	X			PERFORM PALLET/IGLOO HAZARDOUS MATERIALS LOAD TESTS
46			X	REFURBISH SUPPORT SYSTEMS IGLOO
				A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM
				B VERIFY OPERABILITY OF FLUID SYSTEM COMPONENTS
				C INSPECT/REPAIR ELECT CABLES/CONNECTORS & FLUID LINES
				D REFURBISH & VERIFY OPERATION OF THE DMS COMPONENTS
				E INSPECT/REPAIR SUBSYSTEM IGLOO MATING SURFACES
				F INSPECT/REPAIR SUBSYSTEM IGLOO STRUCT STRESS/DAMAGE
47			X	REMOVE EXPERIMENTS, CABLES, LINES & BRACKETS FROM PALLET/IGLOO
48			X	REFURBISH/RECONFIGURE PALLET AND IGLOOS
				A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM
				B VERIFY OPERABILITY OF FLUID SYSTEM COMPONENTS
				C VERIFY OPERABILITY OF PALLET/IGLOO POWER CONDITIONING SYSTEM
				D INSPECT/REPAIR PALLET/IGLOO ELECTRICAL CABLES/CONNECTORS & FLUID LINES
				E INSPECT/REPAIR PALLET/IGLOO MATING SURFACES
				F INSPECT/REPAIR PALLET STRUCT STRESS DAMAGE

experiment system the timelines developed in this study reflect an installation and functional checkout of experiment equipments in rack/rack sets at the payload integration site.

- A Spacelab support systems simulator will be used during experiment integration (Level III) in all processing concepts. Simulators will be used to reduce *ON-time* of the flight hardware; negate the requirement for shipment of flight support systems from the launch site in Concepts II, III, IV, VI, VII, and VIII; and reduce the complement of support modules and systems igloos required to support the anticipated Spacelab traffic model.

- An Orbiter interface simulator will be used during Spacelab integration (Level II) in all processing concepts.

- Level III experiment integration tests are confined to integration and functional checkout of experiment systems which include the complete experiment complement, racks, rack sets, and experiment support equipment. The principal investigator (PI) is assumed to play a strong role during these tests. Minimal allowance for troubleshooting individual experiments has been made in the formulation of the test timelines. It is presumed that the individual experiment systems have been debugged, and that only integration problems between experiments might be encountered.

- Operation of deployment booms and equipment specifically designed for zero-g conditions may be required during checkout. Special GSE to accomplish this type of checkout will be furnished by the PI.

- Level II integration tests shall consist of a functional checkout of the interfaces between the integrated experiment equipments and the Spacelab support systems. When applicable, compatibility of Orbiter-experiment systems interfaces will be verified by utilizing the Orbiter interface simulator. Orbiter-Spacelab interface compatibility demonstrations are not required during the operational era of these two elements.

- On-board checkout capability will be utilized throughout the hardware integration process. Functional checkouts that reflect planned flight operations will be emphasized.

- Repeat testing will be minimized. Functional tests, even after major equipment moves, will be limited to verification of interfaces established at the next assembly level. Verified flight interfaces need not be interrupted for shipping/transportation purposes.

- Integrated payload environmental compatibility will be verified/certified by analysis and similarity to previous payloads, except for EMI.' EMC will be assessed during combined systems tests that are part of Level III integration activities.

- Level I integration includes Orbiter-cargo integration, launch, landing, and Orbiter-cargo disassembly activities. The integrated payload/Spacelab design, test requirements, installation/removal procedures, and test procedures shall conform to the schedule constraints of the Shuttle turnaround plan.

4.2 TEST FLOW DEVELOPMENT

The test flows for both the complete Spacelab and the pallet-only configurations were developed utilizing the three-step method illustrated in Figure 4.2-1.

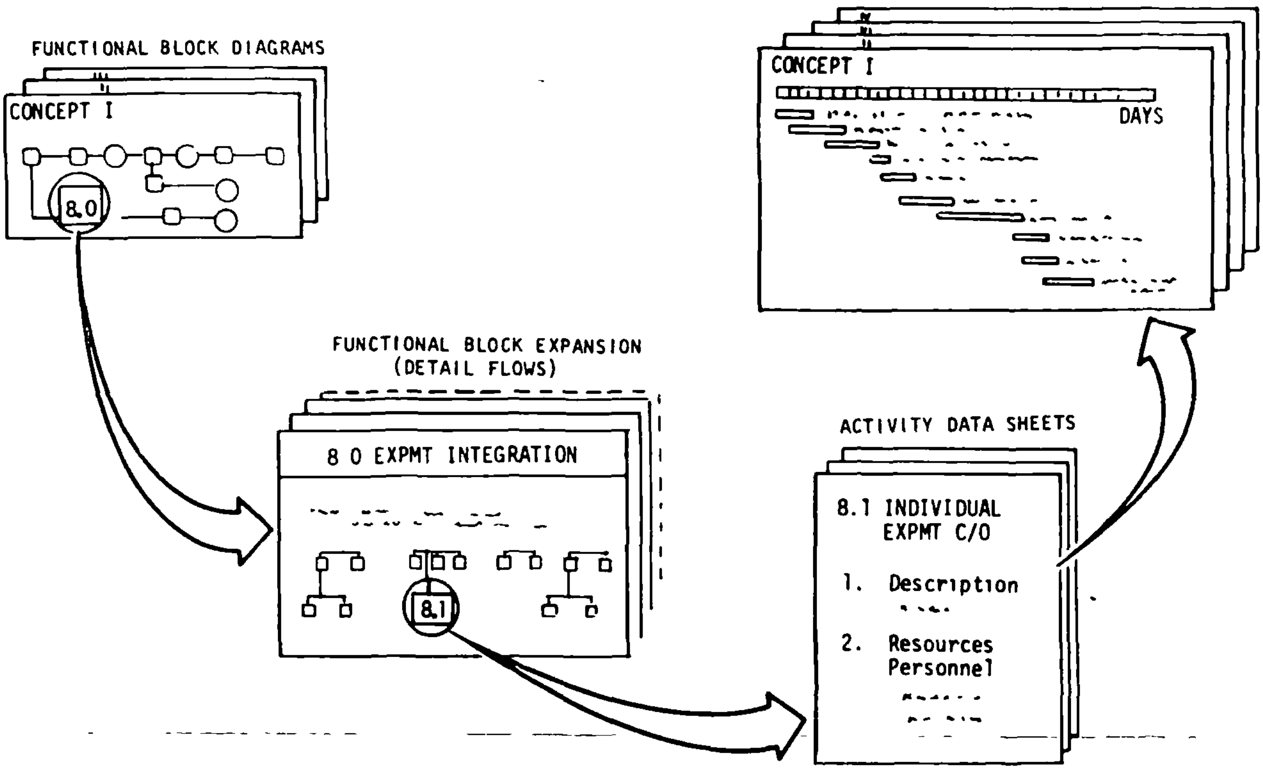

Figure 4.2-1. T&O Test Flow Development

Step 1 established a top-level functional block diagram for each of the eight processing concepts. These block diagrams were derived from hardware processing scenarios that were synthesized to identify the assembly, test, and transportation activities associated with each concept. The scenarios and, thus, the block diagrams, were sequenced in the required order of accomplishment and reflect all hardware ground processing activities. Site location, involved centers, and integration levels were identified on the diagrams.

Step 2 consisted of the expansion of the functional blocks to at least two levels of detail: (1) detailed flows, and (2) activity data sheets. This expansion is illustrated in Figure 4.2-1 for function block 8.0, *Experiment Integration*. The detailed flows were time-sequenced to provide the basis for determination of the total duration of the processing cycle. At this level

of detail, the only overlapping and/or paralleling of effort considered was within the activities of a functional block. Activity data sheets were prepared that provide a narrative description of each of the activities in the detail flows. The activity data sheets provide the basis for estimating manpower, GSE, and facility requirements for each test and operations activity. The descriptors and resource requirement definitions of the activity data sheets facilitated the overlap/parallel scheduling of some test and operations tasks.

Step 3 time-phased the individual detail flows into an integrated test and operations sequence for each concept. With the descriptors and resource requirement definitions of the activity data sheets, additional overlapping/paralleling of activities was accomplished at the functional block level. The integrated flows reflect the optimized cycle for the pre-flight and post-flight processing of all the flight hardware.

The following paragraphs define how the individual test and operations activities were determined, and the process by which they were combined to form the composite set of integrated flows for both the complete Spacelab and the pallet-only processing concepts.

COMPLETE SPACELAB

The complete Spacelab data, presented in this section, relate to the five concepts previously established under "Concept Development" (Volume I, Section 3.0). The detailed flows and activity data sheets for the complete Spacelab are presented in Appendix D (Part I). The following paragraphs illustrate the test flow development for each of the five complete Spacelab concepts.

<u>Functional Block Diagram</u>

Scenarios describing all of the test and operations activities were made for each of the five complete Spacelab processing concepts. Figure 4.2-2 relates to Concept IV, and is an example of the scenarios developed. This scenario illustrates the piggyback transport method utilizing a 747-type aircraft. However, the sequence of operations is equally applicable to the C-5A transport method with very minor time and sequence variations. From these scenarios, the complete set of functional blocks (for all concepts) were defined. There are 22 functional blocks that were identified as being required to complete the test and operations activities for all five complete Spacelab concepts. Table 4.2-1 contains a listing of all 22 possible functional blocks including their titles and respective WBS numbers. The blocks are not numerically listed, but are arranged by WBS number within the three levels of integration.

Block 13.0, *Mission Operations*, was included as a reference for completeness of the processing cycle. It includes those activities from Shuttle lift-off through Orbiter touchdown. The operations for this block were not expanded because they are not a part of the integration and checkout activities. All 22 functional blocks are not utilized in each of the complete Spacelab processing concepts. The explanation of the baseline for each concept will illustrate the applicability of a functional block to a particular concept.

Figure 4.2-2. Spacelab Processing Scenario for Concept IV

Table 4.2-1. Complete Spacelab Functional Block Identification

INTEG LEVEL	WBS NUMBER	BLOCK NO.	FUNCTIONAL FLOW TITLE
III	60-00-50-1.0	1.0	EXPERIMENT SHIPMENT
	-2.0	2.0	EXPERIMENT INSTALLATION
	-3.0	3.0	CONNECT SM INTERFACE SIMULATOR
	-4.0	4.0	EXPERIMENT INTEGRATION
	-5.0	5.0	GSE DISCONNECT
	-6.0	6.0	RACKS/PALLET SHIPMENT
	-18.0	18.0	RACKS/PALLET SHIPMENT
	-19.0	19.0	REFURBISH RACKS/PALLET
	-20.0	20.0	EXPERIMENT SHIPMENT
	-22.0	22.0	POST-REFURBISHMENT RACKS/PALLET SHIPMENT
II	63-00-50-7.0	7.0	MATE RACKS/PALLET-EM/SM SHELLS
	-8.0	8.0	COMPLETE SPACELAB INTEGRATION
	-9.0	9.0	COMPLETE SPACELAB SHIPMENT TO LAUNCH SITE
	-10.0	10.0	COMPLETE SPACELAB OFFLOAD
	-15.0	15.0	COMPLETE SPACELAB MOVE TO MSOB
	-16.0	16.0	COMPLETE SPACELAB SHIPMENT FROM LAUNCH SITE
	-17.0	17.0	DEMATE EM/SM SHELLS
	-21.0	21.0	REFURBISH SUPPORT SYSTEMS & EM/SM SHELLS
I	66-00-50-11.0	11.0	ORBITER CARGO INTEGRATION
	-12.0	12.0	LAUNCH OPERATIONS
	-13.0	13.0	MISSION OPERATIONS (REFERENCE)
	-14.0	14.0	POST-FLIGHT OPERATIONS

Concept I

This concept utilizes the IC as the owner of all the complete Spacelab hardware elements and the location for both Levels III (experiment) and II (Spacelab) integration. Figure 4.2-3 illustrates the specific T&O tasks required for the ground processing of Concept I. The lines connecting the blocks describe the sequence of operations and the hardware flow paths. Concept I operations begin with Block 1.0, *Experiment Shipment from the user.* The next four blocks (2.0, 3.0, 4.0, 5.0) are related to Level III (experiment) integration. Within each of the functional block number boxes, there is a Roman numeral that indicates which level of integration is supported by that particular activity (i.e., Block 8.0 contains the activities related to Level II--Spacelab integration; and Block 5.0, *GSE Disconnect*, contains those operations related to Level III--experiment integration). The caption at the top of each functional block identifies the center responsible for the accomplishment of that particular block. Above four of the blocks (1.0, 9.0, 16.0 and 22.0) there are two centers shown because these four blocks pertain to the shipment of the complete Spacelab hardware end items between centers. For example, Block 9.0 is shown to involve both the LS/IC because Block 9.0 contains the test and operations activities relating to the shipment of the integrated (Level II--completed) complete Spacelab from the IC to the LS. As discussed previously, not all tasks contained in Table 4.2-1 are utilized

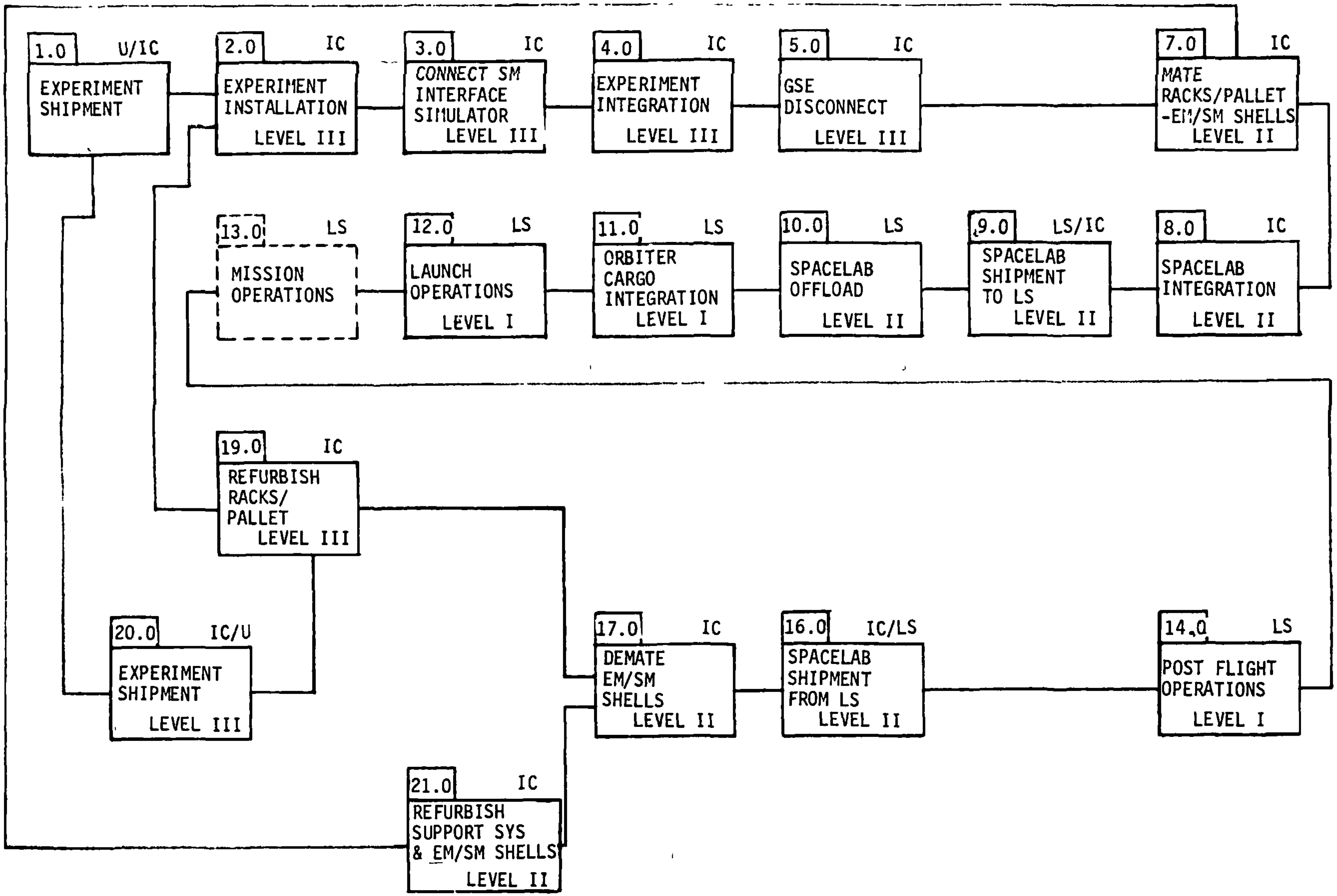

Figure 4.2-3. Concept I Functional Block Diagram

in each of the five complete Spacelab concepts. A comparison of Figure 4.2-3 and Table 4.2-1 will show that Blocks 6.0, 15.0, 18.0, and 22.0 are not required in Concept I for the following reasons.

Block 6.0 - Racks/Pallet Shipment. The racks and pallet are mated with and installed in the SM/EM assembly following experiment integration, and the complete Spacelab is shipped to the launch site from the integration center in a near-flight configuration.

Block 15.0 - Complete Spacelab Move to MSOB. Since the complete Spacelab integration was performed at the integration center, after Orbiter landing the complete Spacelab is removed from the Orbiter cargo bay in the OPF and shipped directly to the IC without processing through the MSOB.

Block 18.0 - Racks/Pallet Shipment. The racks and pallet are shipped from the LS to the IC as part of the complete Spacelab configuration; therefore, no separate shipment is required.

Block 22.0 - Post-Refurbishment Racks/Pallet Shipment. This task applies only to Concept III, where refurbishment of the racks and pallet occurs at the IC and they are shipped to the user site for Level III integration.

Concept II

Following the procedures established above for Concept I, the specific tasks from the total set of processing activities (Table 4.2-1) that apply to Concept II are shown in Figure 4.2-4. It should be noted that Blocks 9.0, 10.0, 16.0, and 22.0 do not apply for the following reasons.

Block 9.0 - Complete Spacelab Shipment to Launch Site. Following experiment integration, only the rack/pallet assembly is shipped to the launch site for integration with the SM/EM assembly. The SM/EM assembly remains at the LS.

Block 10.0 - Complete Spacelab Offload. Complete Spacelab offload does not apply for this concept since the complete Spacelab is not shipped to the launch site.

Block 16.0 - Complete Spacelab Shipment from Launch Site. The SM/EM assembly remains at the launch site; only the rack/pallet assembly is shipped to the IC.

Block 22.0 - Post-Refurbishment Racks/Pallet Shipment. As previously indicated in Concept I, this task applies only to Concept III.

Concept III

The tasks from Table 4.2-1 that apply to Concept III are shown in Figure 4.2-5. From the figure, it is evident that Blocks 9.0, 10.0, and 16.0 do not apply for the same reasons specified for these tasks under Concept II.

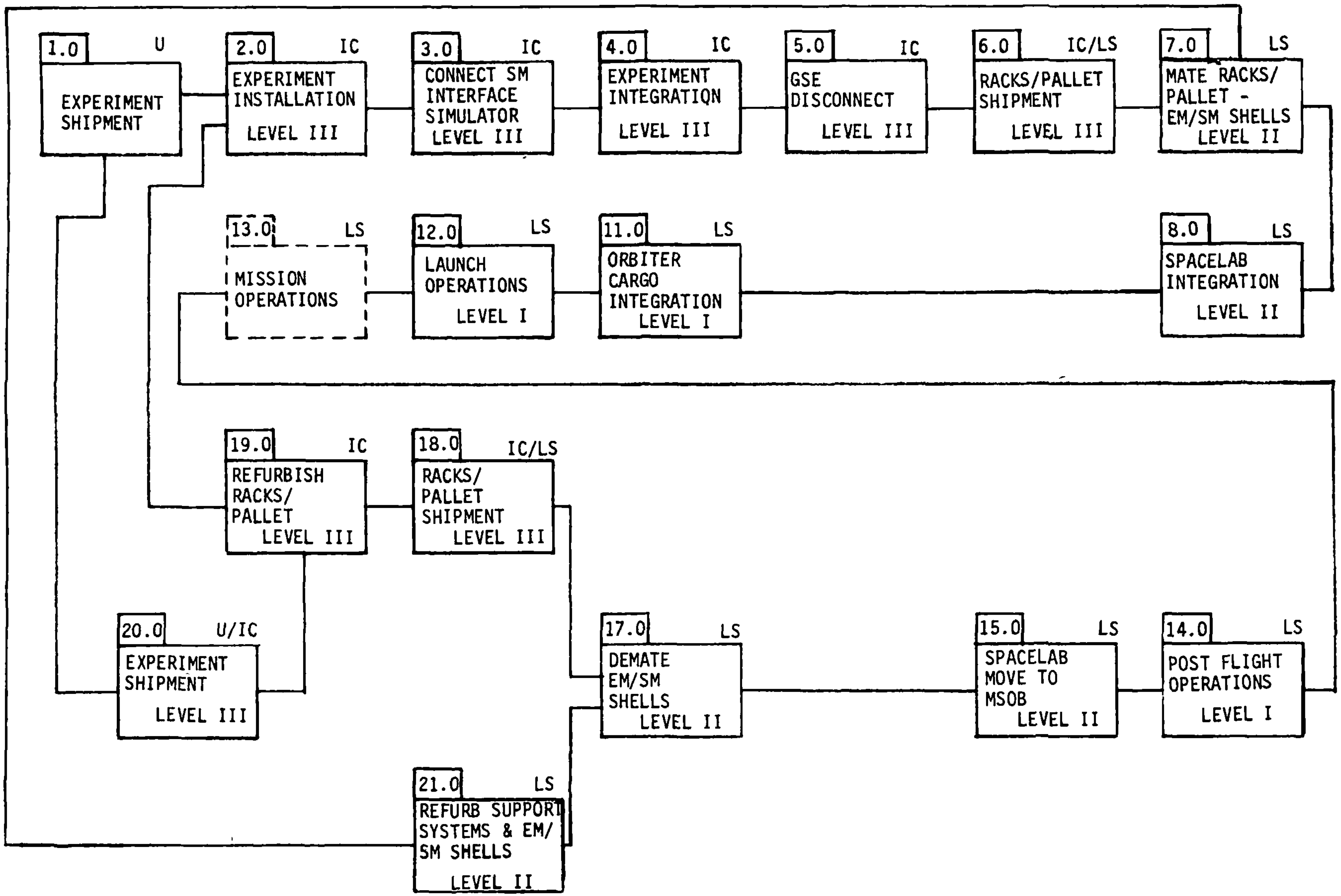

Figure 4.2-4. Concept II Functional Block Diagram

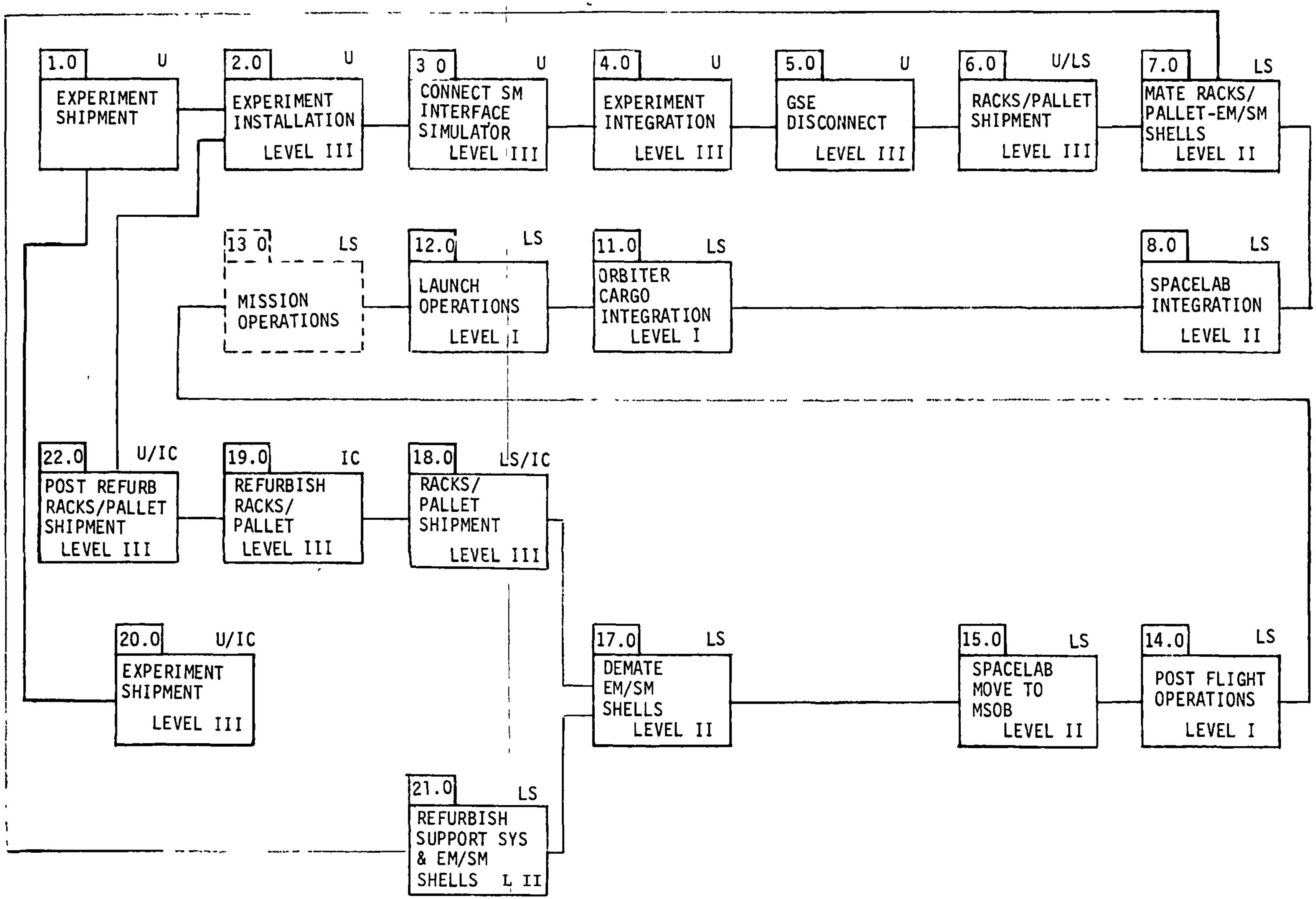

Figure 4.2-5. Concept III Functional Block Diagram

Concept IV

The tasks from Table 4.2-1 that apply to Concept IV are shown in Figure 4.2-6. It is seen that Blocks 9.0, 10.0, 16.0, and 22.0 are not applicable to this concept for the reasons stated under Concept II. In Block 18.0, the rack/pallet assembly is shipped to the user site instead of the IC.

Concept V

Table 4.2-1 tasks, applicable to Concept V, are shown in Figure 4.2-7. Blocks 6.0, 15.0, 18.0 and 22.0 do not apply for the reasons given under Concept I for these same tasks. Note that in Concept V the user center assumes the role of the IC in Concept I.

Detail Flows

Figure 4.2-8 is an example of one of the detail flows which shows the level at which the tests/operations are defined for each of the functional blocks. Each asterisk shown between the integers at the top of the detail flows represent one hour of an 8-hour work day utilized as the baseline for the study. Also, the asterisks in front of each task title represent one hour. Thus, the time estimate for each task is also indicated. Where applicable, during Orbiter/Spacelab operations at the launch site, there are periods of time when the complete Spacelab is operating under the 16-hour/day Orbiter schedule. Where they occur, each of these periods is marked on the affected detail flow. Utilizing the asterisks above the individual task description/titles, and the asterisks preceding the title, the estimated task duration for each individual operation as well as the composite time duration for the entire block can be determined. For example, the third task shown, *Move Spacelab to Orbiter Processing Facility (OPF)*, was estimated to take 2 hours; therefore, the task description is preceded by two asterisks that are shown to occur during the sixth and seventh hours of the first working day of Block 11.0.

Activity Data Sheets

The activity data sheets (ADS) are expanded definitions of each task that is part of a detail flow. In all cases, the detail flows represent expansions of the top-level functional blocks. The ADS were written to define operations and resource requirements at the lowest level of detail described by the detail flows. Figure 4.2-9 is an example of an activity data sheet that contains the tasks and operations for the preparations for and movement of the complete Spacelab to the OPF. This example details the first seven hours of tasks of the overall complete Spacelab operation, Block 11.0, *Orbiter Cargo Integration*. The detail flows and the activity data sheets for all applicable functional blocks of each concept were used to develop the integrated flows for each concept. The activity data sheets contain descriptions of the tasks, and the personnel, GSE and facilities necessary to complete the reference block.

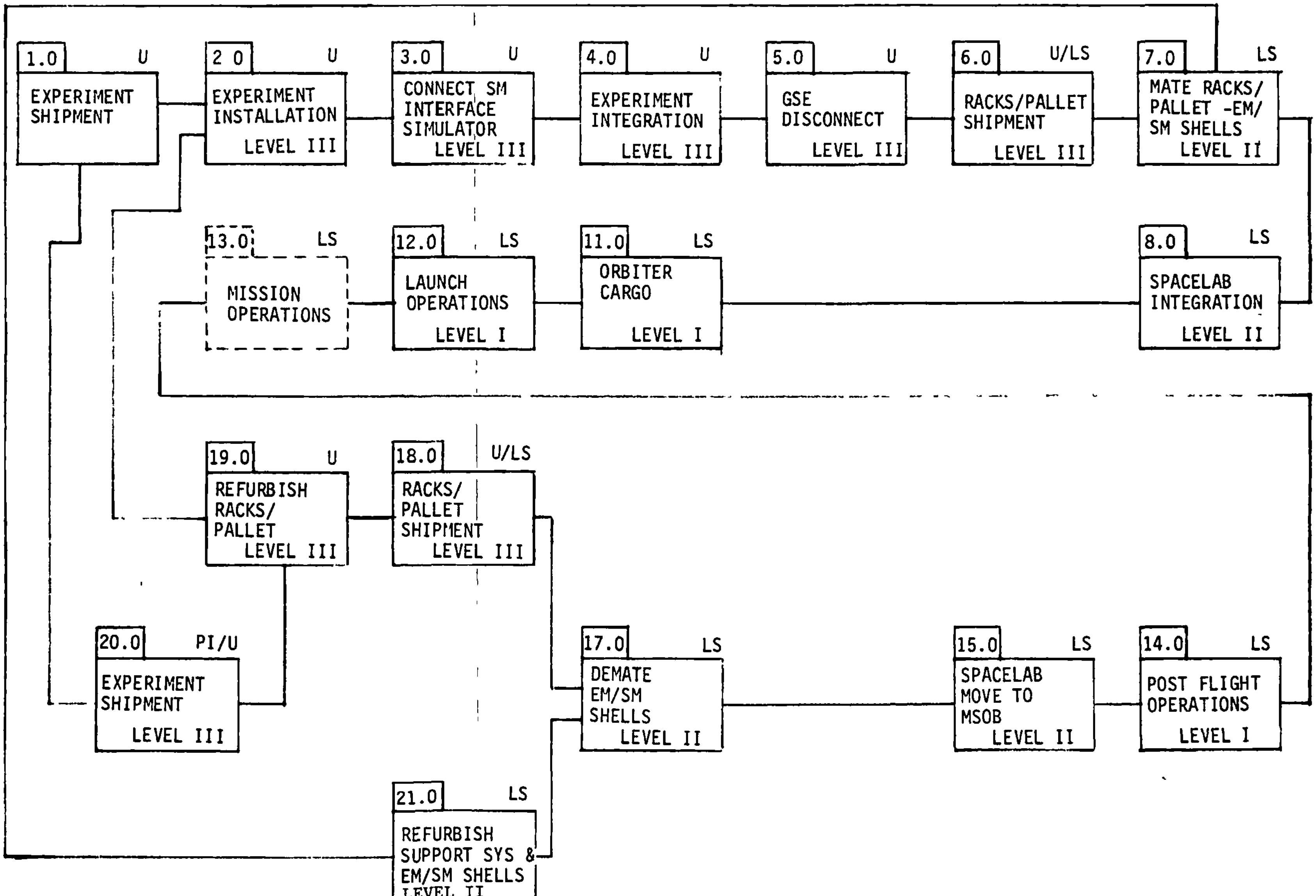

Figure 4.2-6. Concept IV Functional Block Diagram

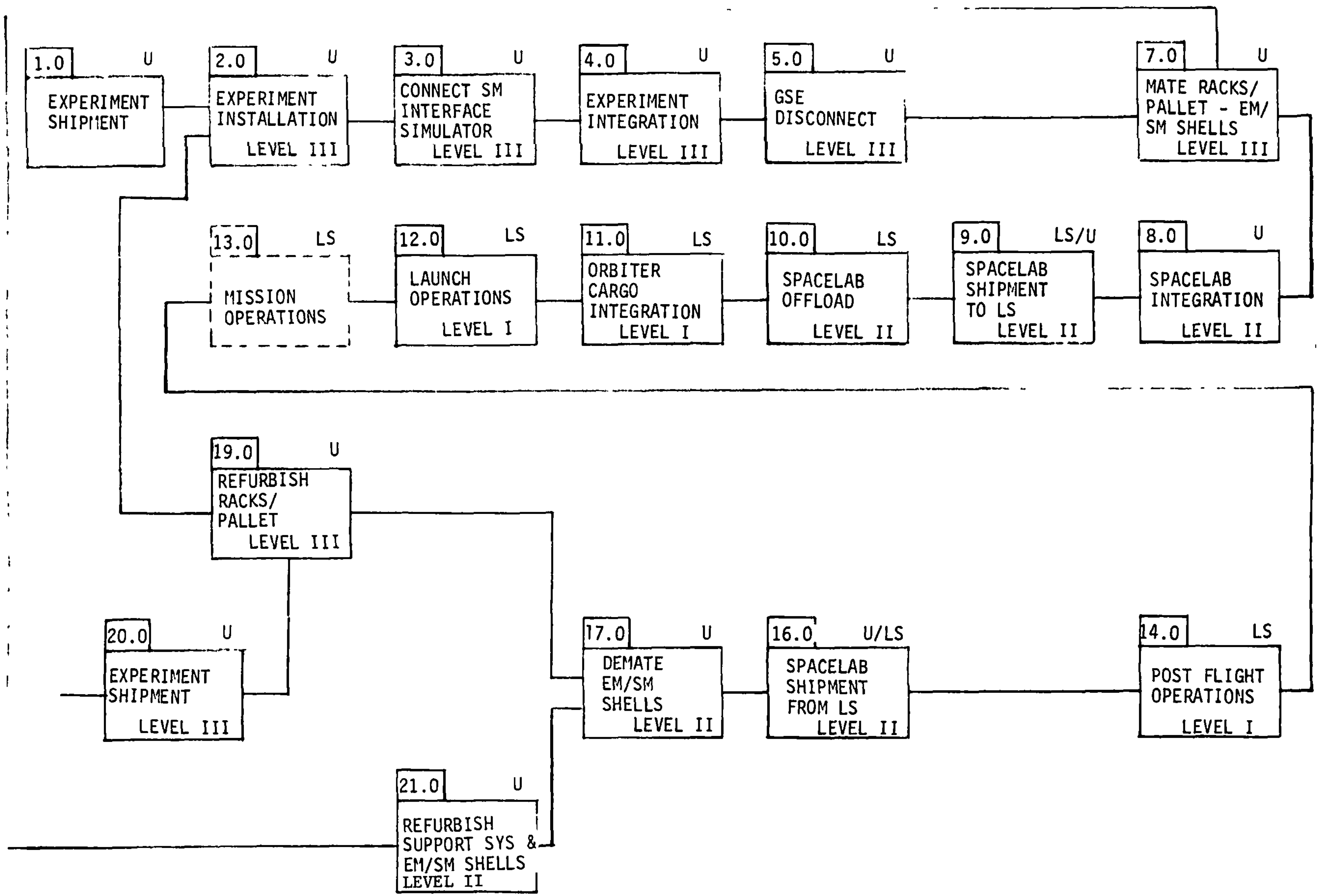

Figure 4.2-7. Concept V Functional Block Diagram

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BLOCK 11.0  ORBITER CARGO INTEGRATION

*******1*******2*******3*******4*******5*******6 WORKING DAYS

***************************** 8 HOUR WORK DAY
***  CONNECT SL LIFTING DEVICE & LOAD SL IN SHIP CNTR/DISCONNECT SL LIFT DEVICES
   **  CONNECT SHIP CNTR LIFT SLING/HOIST & LOAD SL/CNTR ON XPORTER
     **  MOVE SL TO ORBITER PROCESSING FACILITY (OPF)
       ****  OFFLOAD SL IN OPF SL/ORBITER LOAD PREP AREA
           **  REMOVE SLING/HOIST
             **  REM SL FR SHIP CNTR, GSE HATCH/SEAL-INSTL H/SEAL PROT CVR-CNCT A/C & GSE
                 LGTS
               **  CK SL/ORBITER I/F CONNECTIONS- ELEC/MECH
                ****  SERVICE SL WITH NON-HAZ FLUIDS & LOW PRESS GAS
                    ****  INSTALL FLT BATTERIES & CHARGERS
             ***********  INSTALL SL RELATED EQUIP IN ORB CREW COMPARTMENT
                        *  VERIFY ORB READINESS TO ACCEPT SL
                        *  REM HATCH SEAL PROT CVR -A/C & GSE LGT'S
                         **  CONNECT LIFTING SLING/HOIST
                           *************  16 HOUR WORK DAY
                           **  INSTALL SL IN ORBITER & SECURE
                            *  REM LIFTING SLING/HOIST
                             *  ORB/SL I/F VERIF(PLUGS OUT CONT-CNCT CABLES/FLD
                                LINES/UMB'S & TUNNEL)
                              ******  CONDUCT ORB INTEG TEST (OIT) WITH SL
                                   *  EMC/RFI TEST W/SL/ORB SYS OPERATING
                                    *  INSTALL/CNCT ORD NOT ACCESSIBLE AT PAD
                                    **  CONDUCT ABBREV SL LK CK OF TUNNEL & HATCH & FINAL
                                        SL CLOSEOUT
                                    **  SL DATA REVIEW & SL FINAL FLT APPROVAL
```

Figure 4.2-8. Example Detail Flow for Block 11.0

Sheet 1 of 1

ACTIVITY DATA SHEET

1.0 ACTIVITY IDENTIFICATION

Functional Flow Number: 11.1 Applicable Concepts:

Title: Preparations for and Moving Complete Spacelab to OPF

Principal Elements: Spacelab/Orbiter/Tunnel

2.0 ACTIVITY DESCRIPTION

This subtask begins with connecting the lifting devices to the complete Spacelab, followed by loading operations into the Spacelab shipping canister, and disconnection of lifting devices. Lifting devices are then connected to the canister for loading on the transporter. A blanket pressure (GN_2) might be placed inside the canister to preclude entry of contaminated air during the move from the MSOB to the OPF. Some Spacelab/experiment configurations may have unique cooling requirements; so for these configurations, special cooling systems may be necessary as part of the shipping canister design. It is clear that one would not have a shipping canister blanket pressure simultaneously with an air-conditioned canister interior; consequently, the Spacelab/experiment configuration is fundamental to the choice of method. The point of this discussion is to emphasize that the move preparations are dependent upon Spacelab/experiment configuration and therefore the estimates used are related to the three reference ATL payloads (see Appendix A).

The actual move of the complete Spacelab to the OPF from the MSOB requires about two hours because of very low transport speeds ($<$ 5 mph) necessary to mitigate road shock.

At the OPF, the complete Spacelab is removed from the shipping canister, after off-load from the transporter, and placed in a suitable Spacelab/Orbiter load preparation work stand. The GSE hatch cover and seal are removed from the SM hatch, and a hatch surface/seal protective cover is installed. Conditioned air and GSE lighting are installed and access stands set up to facilitate complete Spacelab preloading operations.

Figure 4.2-9. Example Activity Data Sheet (Block 11.0)

Integrated Flows

The integrated flows for all five complete Spacelab concepts are shown in Figure 4.2-10. Complete Spacelab concepts I and V are related in that they involve the completion of all operations (other than Level I integration and the launch) at one center, the IC and user site, respectively. In the other three concepts the SM and EM shell are owned and maintained at the launch site. Both Levels II and I integration are accomplished at the launch site. Because of the variations between these groups of concepts, the most efficient method to illustrate significant differences while not losing the perspective of important similarities, was to group the flows together in the manner shown in Figure 4.2-11. The top portion of the integrated flow pertains to the test and operations activities for Concepts I and V, and the bottom portion illustrates Concepts II, III, and IV.

The initial 12.2 weeks of activities are common to all five complete Spacelab processing concepts. It is at this point that Concepts II, III, and IV deviate from Concepts I and V. Following the dashed-line down from the top flow will illustrate how the integrated flows for Concepts II and IV were defined. The bottom section of this figure contains the unique steps that differentiate Concept III from Concepts II and IV. The final five steps relate to the preparations for and the shipment of the racks, floor structure, aft bulkhead, and the pallet sections to the user's facility following refurbishment. The steps also include the shipment period (two days) and the receiving/inspection effort at the user's facility.

The integrated flows were developed from the detail flows for each concept with proper allowances for work activities that can be accomplished in parallel. From the figure, Concepts I and V have the same processing flow timelines of 111.3 work days (single-shift 8-hour/day, 5-day/week schedule); this equates to 22.3 calendar weeks. Concepts II and IV also have the same processing cycles that equate to 115.8 work days, or 23.2 calendar weeks. Concept III is unique in that its processing cycle is 122.3 work days (24.5 calendar weeks), or approximately 2 weeks longer than for Concepts I and V.

Summary of Processing Times

A comparison of the basic test and operations processing times for all five complete Spacelab concepts is shown in Table 4.2-2. These times were established from the detail flows and the activity data sheets. Three time entries are presented. They are as follows.

1. The basic block time (in work days) required to complete a given functional block.

2. A column indicating the overlap times between functional blocks. For example, 2.5 days of the 5.7 days required for Block 3.0, *Connect SM Interface Simulator*, can be accomplished during the initial steps of Block 4.0. Therefore, only 3.2 days of serial processing time are included in the summary processing times for any concept that uses this block.

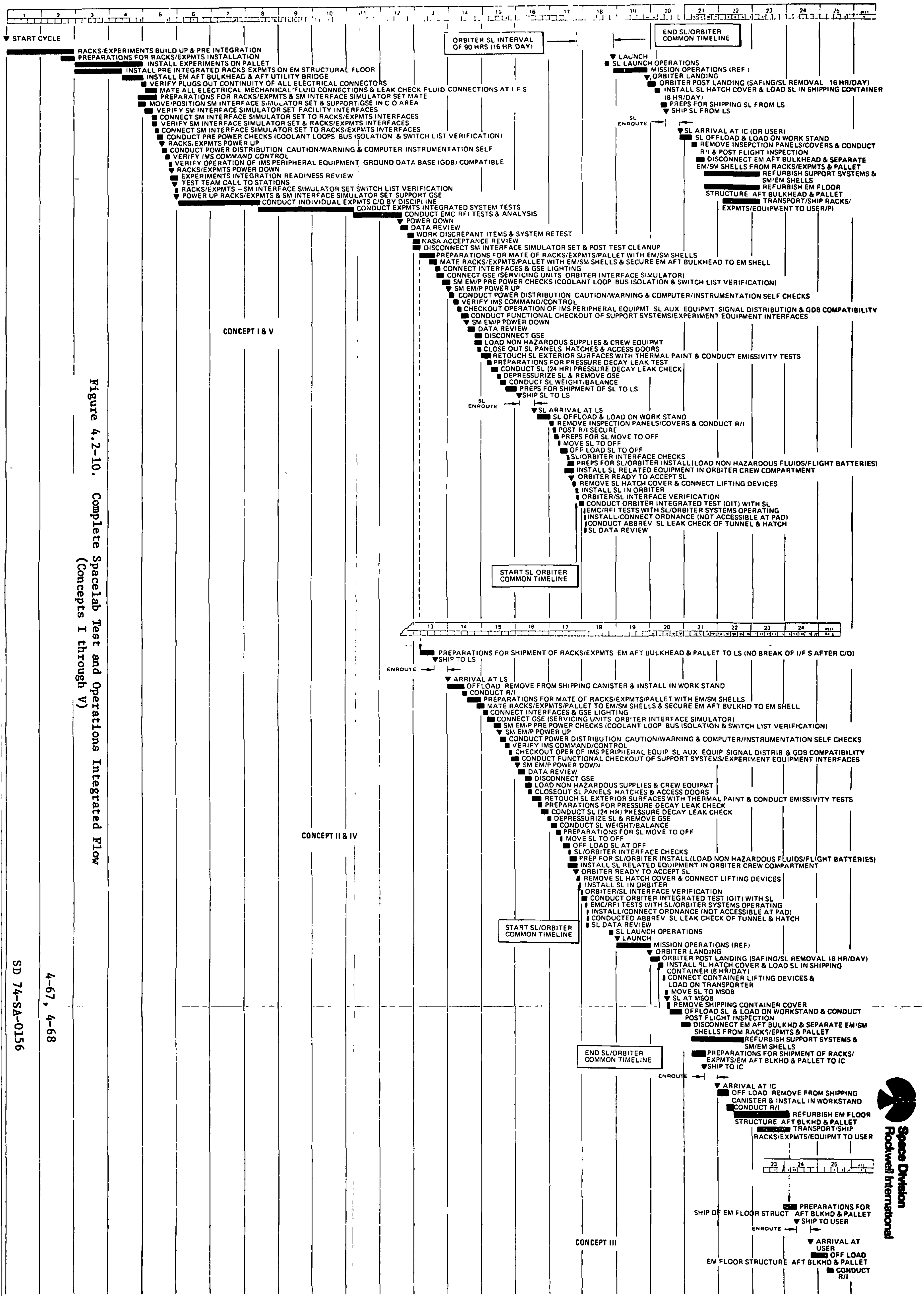

Figure 4.2-10. Complete Spacelab Test and Operations Integrated Flow (Concepts I through V)

Table 4.2-2. Summary of Complete Spacelab Processing Times

BLOCK	MAJOR FUNCTIONAL ACTIVITY	BLOCK TIME (DAYS)	OVERLAP TIME	PARALLEL TIMES	SERIAL PROCESSING TIMES				
					I	II	III	IV	V
1.0	EXPERIMENT SHIPMENT	6.0		X					
2.0	EXPERIMENT INSTALLATION	22.0			22.0	22.0	22.0	22.0	22.0
3.0	CONNECT SM INTERFACE SIMULATOR	5.7	2.5		3.2	3.2	3.2	3.2	3.2
4.0	EXPERIMENT INTEGRATION	36.0			36.0	36.0	36.0	36.0	36.0
5.0	GSE DISCONNECT	0.9		X					
6.0	RACKS/PALLET SHIPMENT	6.7				6.7	6.7	6.7	
7.0	MATE RACKS/PALLET-EM/SM SHELLS	3.0			3.0	3.0	3.0	3.0	3.0
8.0	SPACELAB INTEGRATION	10.4			10.4	10.4	10.4	10.4	10.4
9.0	SPACELAB SHIPMENT TO LAUNCH SITE	3.6			3.6				3.6
10.0	SPACELAB OFFLOAD	2.7			2.7				2.7
11.0	ORBITER CARGO INTEGRATION	4.7	0.2		* 4.5	4.7	4.7	4.7	* 4.5
12.0	LAUNCH OPERATIONS	4.2			4.2	4.2	4.2	4.2	4.2
13.0	MISSION OPERATIONS (REF)	5.0			5.0	5.0	5.0	5.0	5.0
14.0	POST-FLIGHT OPERATIONS	1.9			1.9	1.9	1.9	1.9	1.9
15.0	SPACELAB MOVE TO MSOB	2.6				2.6	2.6	2.6	
16.0	SPACELAB SHIPMENT FROM LAUNCH SITE	5.4			5.4				5.4
17.0	DEMATE EM/SM SHELLS	1.2			1.2	1.2	1.2	1.2	1.2
18.0	RACKS/PALLET SHIPMENT	6.7				6.7	6.7	6.7	
19.0	REFURBISH RACKS/PALLET	8.2			8.2	8.2	8.2	8.2	8.2
20.0	EXPERIMENT SHIPMENT	5.5		X					
21.0	REFURB SUPPORT SYST & EM/SM SHELLS	8.2	8.2	X					
22.0	POST-REFURB RACKS/PALLET SHIPMENT	6.5					6.5		
	TOTAL (WORK DAYS)	157.9	2.7	28.1	111.3	115.8	122.3	115.8	111.3
		TOTAL CALENDAR WEEKS			22.3	23.2	24.5	23.2	22.3
		TOTAL CALENDAR MONTHS			5.6	5.8	6.1	5.8	5.6

*OVERLAP TIME APPLICABLE TO CONCEPTS I & V ONLY

3. A column indicating parallel functional block activities. These blocks can be completely accomplished in parallel with other blocks and, as such, are not added to the composite overall complete Spacelab processing times. For example, functional block 1.0, *Experiment Shipment*, can be accomplished during post-flight refurbishment of Spacelab flight hardware.

   Block 13.0, *Mission Operations*, is included for reference. The baseline mission duration was 7 days, but the T&O time estimates were developed from a single-shift 8-hour/day 5-day/week; therefore, to avoid potential confusion in converting from work days to calendar time, the one week of the mission has been defined as 5 days of serial processing time.

   The majority of the operations to be performed in any given concept is essentially the same. The significant differences between concepts are as follows.

   a. Concept III varies from Concepts II and IV by the additional 6.5 days required to ship the rack/pallet assembly to the user following refurbishment at the IC. This activity is unique to Concept III.

   b. Concepts II and IV vary from Concepts I and V by approximately 4.5 days. Concepts II and IV are longer because of two operations: (1) shipment of the complete Spacelab to the MSOB following a mission, where the complete Spacelab elements are demated and the rack and pallet prepared for shipment to the IC (an additional 2.6 days); and (2) shipment of racks and pallet is a 6.7-day operation, whereas complete Spacelab shipment is accomplished in 5.4 days.

The remainder of the time difference between these concepts is due to small differences that result from parallel activity consequent to handling of the mated complete Spacelab (Concepts I and V), as opposed to the handling of separate Spacelab elements (rack/pallet assembly-SM/EM shell) of Concepts II and IV.

Complete Spacelab Test and Checkout Requirements

The composite set of test and checkout requirements (TCR) for the complete Spacelab are listed in the TCR matrix of Table 4.2-3. As shown in the table, each test requirement is cross-referenced to the work breakdown structure (WBS) under which the responsibility and costs for that item are collected. Further, each test requirement is identified against the particular functional block in which it is accomplished, along with its test integration level. The functional flow blocks that are necessary in the processing cycle, but which do not specifically generate test requirements are itemized in the footnotes of

Table 4.2-3. Complete Spacelab TCR Matrix

LINE ITEM	WBS REF NO	INTEGRATION LEVEL I	II	III	TEST/CHECKOUT REQUIREMENT	FUNCTIONAL FLOW BLOCK NUMBER* EXPERIMENT INSTALLATION 2.0	CONNECT SM INTERFACE SIM 3.0	EXPERIMENT INTEGRATION 4.0	MATE RACKS/PALLET -EM/SM SHELLS 7.0	SPACELAB INTEGRATION 8.0	ORBITER CARGO INTEGRATION 11.0	LAUNCH OPERATIONS 12.0	REFURBISH RACKS/PALLET 19.0	REFURB SUPPORT SYS. & EM/SM SHELLS 21.0
1	600502			X	VERIFY PLUGS-OUT CONTINUITY OF RACKS/EXPMTS/EQUIP	X								
2	600502			X	LEAK-CHK FLUID CONNECTIONS AT AFT BLKHD & PALLET I/F'S	X								
3	600503			X	VERIFY SM I/F SIM MECH/ELECT CONNECTIONS WITH FACILITY		X							
4				X	VERIFY SM I/F SIMULATOR/RACKS/PALLET INTERFACES		X							
5				X	VERIFY SERV UNIT FLOW & CONTROL TO R/P COOLANT LOOPS		X							
6				X	PERFORM BUS ISOLATION TESTS OF RACKS/EXPMTS/PALLET		X							
7				X	PERFORM ELECTRICAL POWER DISTRIBUTION TEST		X							
8				X	VERIFY CAUTION/WARNING CIRCUITRY		X							
9				X	PERFORM COMPUTER & INSTRUMENTATION SYST SELF-CHECKS		X							
10				X	VERIFY DMS COMMAND & CONTROL & PERIPHERAL EQUIPMENT		X							
11				X	VERIFY GRND DATA BASE (GDB) COMPAT VIA GDB UMBILICAL		X							
12	600503			X	VERIFY RACKS/EXP AUX EQUIP--CCTV, INTERCOM, ETC		X							
13	600504			X	VERIFY READINESS OF EXPMT OR SUPT EQUIP FOR ACTIVATION			X						
14				X	ACTIVATE CONTROL & DISPLAYS & SUPPORT EQUIPMENT			X						
15				X	VERIFY PERF OF C/D CONSOLE DURING EXPMT FUNCT C/O			X						
16				X	VERIFY OPER OF PALLET-MOUNTED DEPLOYABLE EXPMT EQUIP			X						
17				X	VERIFY OPER OF RACK-MOUNTED MECHANICAL EXPMT EQUIP			X						
18				X	VERIFY FUNCT OPERATION OF EXPERIMENTS/SUPPORT EQUIPMENT			X						
19				X	VERIFY DATA PROCESSING/RECORDING EQUIP DURING EXPMT C/O			X						
20	600504			X	CONDUCT EMI/RFI TESTS			X						
21	630507		X		CONDUCT SM/EM/PALLET ELECT BONDING CHECKS AFTER COMPLETE SPACELAB (SL) ASSEMBLY				X					
22	630507		X		CONDUCT & VERIFY ALL COMPLETE SL ELEC/MECH INTERFACES				X					
23	630508		X		SERVICE & VERIFY COOLANT FLOW THROUGH GSE					X				
24			X		VERIFY ORBITER INTERFACE SIM OPERATIONAL CAPABILITY					X				
25			X		PERFORM COMPLETE SPACELAB BUS ISOLATION TESTS					X				
26			X		CONDUCT COMPLETE SL ELECTRICAL POWER DISTRIB TESTS					X				
27			X		VERIFY COMPLETE SPACELAB C&W CIRCUITRY					X				
28			X		CONDUCT COMPLETE SPACELAB COMPUTER SELF-CHECKS					X				
29			X		VERIFY COMPLETE SL DMS CMD/CONTROL & PERIPHERAL EQUIP					X				
30			X		VERIFY COMPLETE SL AUX EQUIP -CCTV, INTERCOM, LIGHTING, ETC					X				
31			X		CHECK OUT SIG DISTRIBUTION VIA SM-ORBITER UMBILICAL					X				
32			X		VERIFY GDB OPERATION VIA GDB UMBILICAL					X				
33			X		CONDUCT FUNCT C/O OF COMPLETE SL SUPPORT SYSTEMS/ EXPMT EQUIPMENT INTERFACES					X				
34			X		CONDUCT EMISSIVITY TESTS OF COMPLETE SL EXTERIOR SURFACES					X				
35			X		CONDUCT COMPLETE SL 24-HR PRESS DECAY LK CHK					X				
36	630508		X		CONDUCT COMPLETE SL WEIGHT/BALANCE TESTS					X				
37	660511	X			PERFORM COMPLETE SL/ORB PREINSTALL INTERF VERIF TESTS						X			
38		X			SERVICE COMPLETE SL WITH NON-HAZ FLUIDS & LOW-PRESS GASES						X			
39		X			VERIFY ORBITER READINESS TO ACCEPT COMPLETE SPACELAB						X			
40		X			PERFORM ORBITER/COMPLETE SL I/F VERIFICATION TEST						X			
41		X			PERFORM ORBITER INTEGRATED TEST (OIT)						X			
42		X			CONDUCT COMPLETE SPACELAB/ORBITER EMI/RFI TESTS						X			
43		X			PERFORM ABBREVIATED LEAK CHECKS A TUNNEL B TUNNEL HATCH C COMPLETE SPACELAB INTERFACES						X			
44	660511	X			PERFORM ORDNANCE INSTALLATION TESTS						X			
45	660512	X			CONDUCT COMPLETE SL FINAL PRELAUNCH TESTS							X		
46	660512	X			PERFORM COMPLETE SL HAZ MATERIALS LOADING TESTS							X		
47	600519 600519			X	REFURBISH RACKS/PALLET A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM B REMOVE RACKS/EXPERIMENTS C REFURBISH RACKS D VERIFY OPERABILITY OF FLUID SYSTEM COMPONENTS								X	
48	600521			X	REFURBISH SUPPORT SYSTEMS AND SM/EM ASSEMBLY A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM B VERIFY OPERABILITY OF FLUID SYSTEM COMPONENTS C VERIFY OPERATION OF AIR REVITALIZATION SYSTEM D VERIFY OPERATION OF DMS COMPONENTS E VERIFY OPERATION OF CPSS (AIRLOCKS, IPS, ETC) AS REQ									X

*NOTE: THE FOLLOWING FUNCTIONAL FLOW BLOCKS INVOLVE SHIPPING, RECEIVING INSPECTION, MATING/DEMATING, INSTALLATION/REMOVAL, MISSION & POST-FLIGHT OPERATIONS WHICH DO NOT CONTAIN ANY TEST & CHECKOUT REQUIREMENTS

- 1.0 EXPERIMENT SHIPMENT
- 5.0 GSE DISCONNECT
- 6.0 RACKS/PALLET SHIPMENT
- 9.0 SPACELAB SHIPMENT
- 10.0 SPACELAB OFFLOAD
- 13.0 MISSION OPERATIONS
- 14.0 POST-FLIGHT OPERATIONS
- 15.0 SPACELAB MOVE TO MSOB
- 16.0 SPACELAB SHIPMENT FROM LAUNCH SITE
- 17.0 DEMATE EM/SM SHELLS
- 18.0 RACKS/PALLET SHIPMENT
- 20.0 EXPERIMENTS SHIPMENT
- 22.0 POST-REFURB RACKS/PALLET SHIPMENT

Table 4.2-3. Refer to Section 4.1 (Composite Requirements Matrix) of this volume for the guidelines and assumptions that were used in the development of the TCR matrix.

PALLET ONLY

The data for the pallet-only processing concepts, described in the following paragraphs, were developed in the same manner as for the complete Spacelab. The data contained herein apply to three additional processing concepts which, for convenience, have been designated in contiguous numerical order with the complete Spacelab concepts (i.e., Concepts VI, VII and VIII). This designation was chosen to reduce the possibility of confusion of concepts between the complete Spacelab and pallet-only configurations. A description of the pallet-only Spacelab configuration is presented in Section 5.0 of Volume I.

Functional Block Diagram

In the same manner as for the complete Spacelab, scenarios of all the processing operations were developed for each pallet-only concept. For the pallet-only concepts, 19 functional blocks were identified as being required to complete the processing cycle. These 19 blocks are illustrated in Table 4.2-4. They are grouped by WBS number and integration level. The 60-00-50-XX entries relate to Level III integration, 63-00-50-XX to Level II, and the 66-00-50-XX entries to Level I.

Table 4.2-4. Pallet-Only Functional Block Identification

WBS NO.	BLOCK NO.	FUNCTIONAL FLOW TITLE
60-00-50-1.0	1.0	EXPERIMENT SHIPMENT
-2.0	2.0	EXPMT INSTALLATION (PALLET/CANISTER)
-3.0	3.0	CONNECT & C/O IGLOO/ORBITER SIMULATOR SET
-4.0	4.0	EXPERIMENT CHECKOUT & INTEGRATION
-5.0	5.0	GSE DISCONNECT
-6.0	6.0	PALLET/IGLOO SHIPMENT
-7.0	7.0	PALLET/IGLOO & PSS EQUIP ARRIVAL & R/I
-15.0	15.0	PALLET/IGLOO SHIPMENT
-16.0	16.0	REMOVE EXPMTS/EQUIPMENT FROM PALLET/IGLOO
-17.0	17.0	EXPERIMENT SHIPMENT
-18.0	18.0	REFURBISH/RECONFIGURE PALLET & IGLOOS
-19.0	19.0	POST-REFURBISHMENT PALLET/IGLOO SHIPMENT
63-00-50-8.0	8.0	MATE PALLET & IGLOO (SUPPORT SYSTEMS)
-9.0	9.0	SPACELAB INTEGRATION
66-00-50-10.0	10.0	ORBITER CARGO INTEGRATION
-11.0	11.0	LAUNCH OPERATIONS
-12.0	12.0	MISSION OPERATIONS (REFERENCE)
-13.0	13.0	POST-FLIGHT OPERATIONS
-14.0	14.0	REFURBISH SUPPORT SYSTEMS IGLOO

Again, as in the complete Spacelab concepts, Block 12.0, *Mission Operations*, has been included (estimated as 5 days) in order to be able to establish the total serial processing time for each of the three pallet-only concepts. The following paragraphs describe which functional blocks and detail flows pertain to each of the three pallet-only concepts.

Concept VI

The specific sequence and applicability of the functional blocks for Concept VI are illustrated in Figure 4.2-11. Note that all the functional blocks contained in Table 4.2-4 apply to this concept. Concept VI is characterized by the ownership of the support systems igloo by the LS, and pallet segments and experiment support canisters by the IC. Level III integration is at the user facility, and Levels II and I integration is at the LS. The transfer of hardware between centers is illustrated by the center designated above a given functional block. Those transitional blocks that involve the shipment of hardware from one center to another have both centers identified above the blocks (i.e., Block 15.0, *Pallet/Igloo Shipment* following the mission, is originated at the LS and concluded at the IC).

Concept VII

The applicable tasks are shown in Figure 4.2-12, which illustrates that Block 19.0, *Post-Refurbishment Pallet/Igloo Shipment*, is not applicable since the IC performs the refurbishment of this hardware and also experiment integration at the same facility.

Concept VIII

The applicable tasks are illustrated in Figure 4.2-13, and Block 19.0 is again not applicable because the user in this concept performs the refurbishment of the pallet/igloo, which is followed by experiment integration at the user's facility. There is no need to ship a refurbished pallet/igloo assembly to another center for Level III integration.

Detail Flows

The detail flows for the three pallet-only concepts were developed in the same manner as those for the complete Spacelab concepts. The flows are time-sequenced expansions of all 19 functional blocks (listed in Table 4.2-4) that are required by the pallet-only concepts.

Activity Data Sheets

The activity data sheets (for the pallet-only concepts) which describe the individual tasks/operations of the detail flows are provided in Appendix D, Part II. Each activity data sheet is coded to indicate concept applicability.

Integrated Flows

Figure 4.2-14 illustrates the integrated flows for the pallet-only concepts. These flows were made from the detail flows of the pallet-only

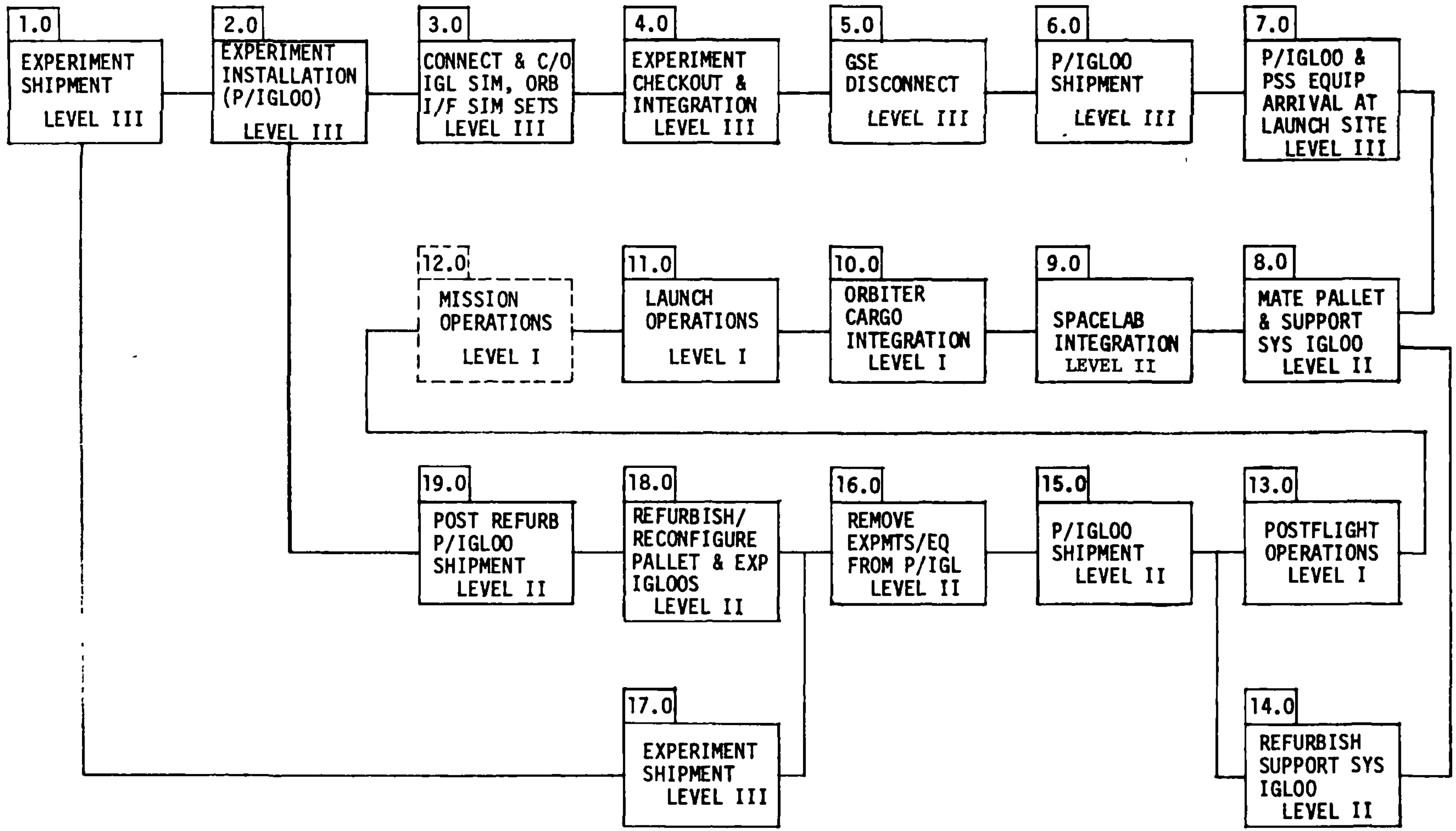

Figure 4.2-11. Pallet-Only Concept VI

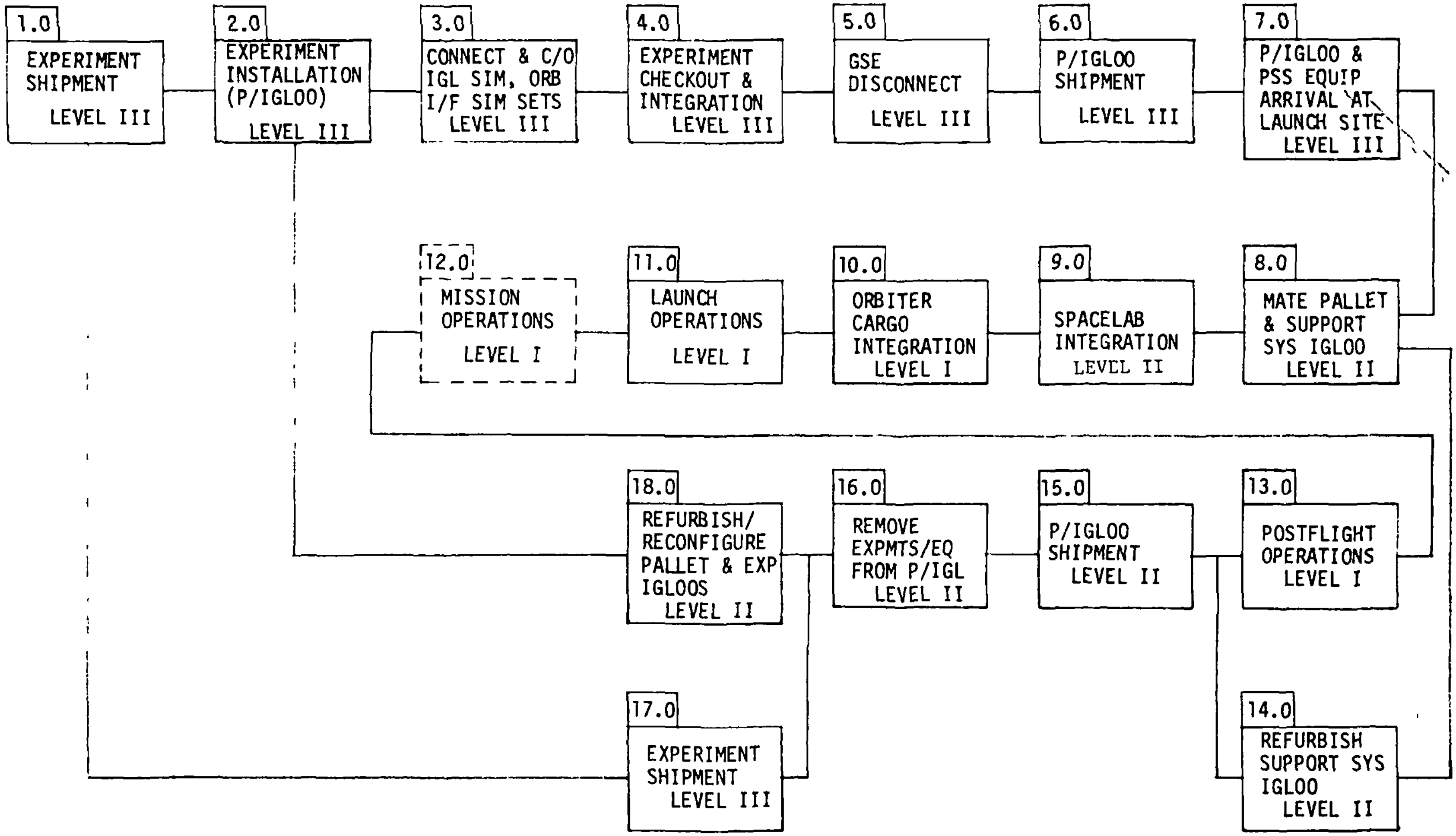

Figure 4.2-12. Pallet-Only Concept VII

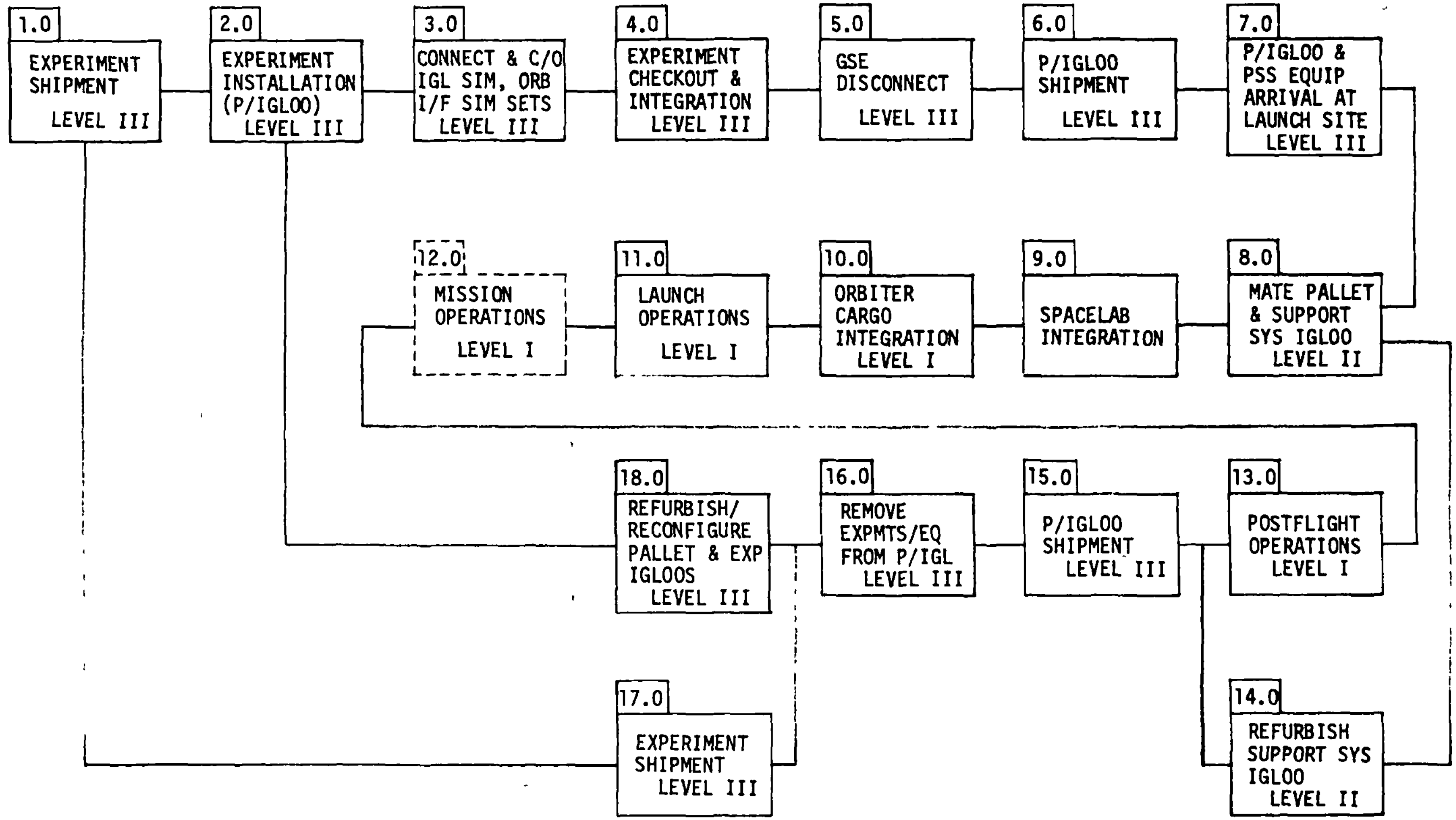

Figure 4.2-13. Pallet-Only Concept VIII

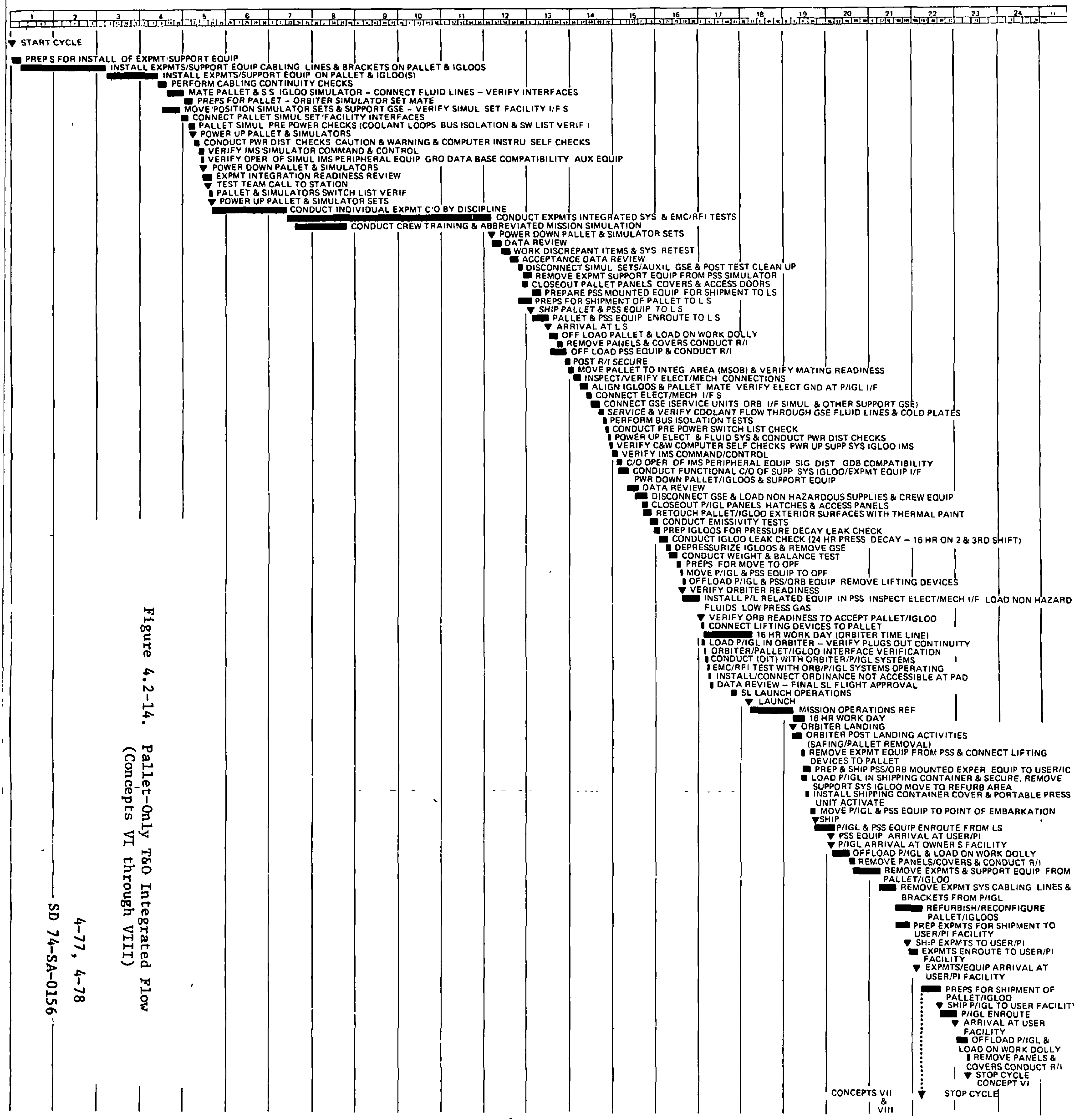

Figure 4.2-14. Pallet-Only T&O Integrated Flow (Concepts VI through VIII)

configuration. The integrated flows consider tasks that can be performed in parallel to minimize the overall processing timelines. The integrated flows for Concepts VII and VIII are identical. The cycle for these two concepts ends with the refurbishment of the pallet segments and experiment equipment canisters. Concept VI includes all the tasks of Concepts VII and VIII plus an additional seven tasks. These additional tasks are illustrated in Figure 4.2-14, after completion of the ground operations cycle for Concepts VII and VIII. The additional tasks involve the preparation and shipment of pallet segments and experiment equipment canisters from the IC to the user center for Level III integration of the payload for a subsequent flight. Post-flight refurbishment and Level III integration are accomplished at the same site in Concepts VII and VIII and, thus, a post-refurbishment shipment is not required in these two concepts. The total processing times for Concepts VII and VIII are identical; the processing time for Concept VI is 5.6 days longer.

Summary of Processing Times

The processing times for each pallet-only concept are illustrated in Table 4.2-5. The processing times are listed for each concept by functional block. Work days required to complete each particular functional block are indicated. Where applicable, overlap time between blocks is indicated. For example, the time required to complete Block 3.0 was estimated to be 5.7 days, but 3.7 days of the activity can be performed in parallel with the subsequent activity (Block 4.0). Therefore, only two additional days are added to the serial processing time estimates. Parallel functional block activities are also indicated. Entries were made for those blocks that are accomplished entirely in parallel with some other functional block; and therefore, do not add any serial processing time to the total for any concept that utilizes these blocks.

The data of Table 4.2-5 indicate that both Concepts VII and VIII require 106.1 work days. For a 5-day/week, 8-hour/day, this equates to 21.2 calendar weeks. Concept VI requires a processing time of 111.7 work days (22.3 calendar weeks), or an additional 1.1 weeks is required to complete those activities related to the seven additional operations involved in the preparation and shipment of the pallet segments and experiment equipment canisters from the IC to the user facility. In Concept VI, these equipment items are refurbished at the IC and sent to the user where Level III integration (experiment installation and checkout) is conducted.

Pallet-Only Test and Checkout Requirements

The composite set of test and checkout requirements for the pallet-only concepts is illustrated in Table 4.2-6. This matrix for the pallet-only concept was developed in a manner identical to the complete Spacelab version (Table 4.2-3). As shown in Table 4.2-6, each test/checkout requirement is cross-referenced to the WBS number under which the responsibility and costs for that item are collected. Further, each test requirement is identified against the particular function block in which it is accomplished along with the associated test integration level. The functional flow blocks that are necessary in the processing cycle, but which do not specifically generate

Table 4.2-5. Summary of Pallet-Only Processing Times

BLOCK	MAJOR FUNCTIONAL ACTIVITY	BLOCK TIME (DAYS)	OVERLAP TIME	PARALLEL TIME	SERIAL PROCESSING TIME		
					VI	VII	VIII
1.0	EXPERIMENT SHIPMENT	7.0/1.0		X			
2.0	EXPMT INSTALLATION (PALLET/IGLOO)	21.0			21.0	21.0	21.0
3.0	CONNECT & C/O IGLOO/ORBITER SIM SET	5.7	3.7		2.0	2.0	2.0
4.0	EXPERIMENT CHECKOUT & INTEGRATION	36.0			36.0	36.0	36.0
5.0	GSE DISCONNECT	2.5		X			
6.0	PALLET/IGLOO SHIPMENT	3.5			3.5	3.5	3.5
7.0	PALLET/IGLOO & PSS EQUIP ARRIV & R/I	2.4			2.4	2.4	2.4
8.0	MATE PALLET & IGLOO (SUPPORT SYSTEM)	2.7			2.7	2.7	2.7
9.0	SPACELAB INTEGRATION	10.2			10.2	10.2	10.2
10.0	ORBITER CARGO INTEGRATION	4.2			4.2	4.2	4.2
11.0	LAUNCH OPERATIONS	4.2			4.2	4.2	4.2
12.0	MISSION OPERATIONS (REF)	5.0			5.0	5.0	5.0
13.0	POST-FLIGHT OPERATIONS	1.9			1.9	1.9	1.9
14.0	REFURBISH SUPPORT SYSTEMS IGLOO	7.5		X			
15.0	PALLET/IGLOO SHIPMENT	5.0			5.0	5.0	5.0
16.0	REMOVE EXPMTS/EQUIP FROM PALLET/IGLOO	5.0			5.0	5.0	5.0
17.0	EXPERIMENT SHIPMENT	2.5		X			
18.0	REFURB/RECONFIG PALLET & IGLOOS	3.0			3.0	3.0	3.0
19.0	POST-REFURB PALLET/IGLOO SHIPMENT	5.6			5.6		
	TOTAL WORK DAYS	134.9/128.9	3.7	17/11	111.7	106.1	106.1
		TOTAL CALENDAR WEEKS			22.3	21.2	21.2
		TOTAL CALENDAR MONTHS			5.6	5.3	5.3

Table 4.2-6. Pallet-Only TCR Matrix

LINE ITEM	WBS REF NO	INTEGRATION LEVEL I	II	III	TEST/CHECKOUT REQUIREMENT	FUNCTIONAL FLOW BLOCK NUMBER* EXPMT INSTALLATION (PALLET/IGLOO) 2 0	CONNECT & CHECKOUT IGLOO/ORBITER SIM SET 3 0	EXPERIMENT CHECKOUT AND INTEGRATION 4 0	MATE PALLET & IGLOO (SUPPORT SYSTEMS) 8 0	SPACELAB INTEGRATION 9 0	ORBITER CARGO INTEGRATION 10 0	LAUNCH OPERATIONS 11 0	REFURBISH SUPPORT SYSTEMS IGLOO 14 0	REMOVE EXPMT/EQUIP FROM PALLET/IGLOO 16 0	REFURB/RECONFIG PALLET/IGLOOS 18 0
1	600502			X	VERIFY PLUGS-OUT CONTINUITY OF EXPERIMENT IGLOOS/EXPERIMENTS/EQUIPMENT	X									
2	600502			X	LEAK CHECK FLUID CONNECTIONS AT PALLET/IGLOO/EXPERIMENT INTERFACES	X									
3	600503			X	VERIFY SUPPORT SYSTEMS IGLOO & ORBITER SIM SETS ELECT/MECH CONNECTIONS WITH FACILITY		X								
4				X	VERIFY SS IGLOO SIM/ORB SIM/EXPMT IGLOO/P INTERFACES		X								
5				X	VERIFY SERVICING UNITS FLOW & CONTROL TO PALLET/IGLOO COOLANT LOOPS		X								
6				X	PERFORM BUS ISOLATION TESTS OF PALLET/IGLOO EXPMTS		X								
7				X	PERFORM ELECTRICAL POWER DISTRIBUTION TESTS		X								
8				X	VERIFY CAUTION/WARNING CIRCUITRY		X								
9				X	PERFORM COMPUTER & INSTRUMENTATION SYS SELF-CHECKS		X								
10				X	VERIFY IMS COMMAND/CONTROL & PERIPHERAL EQUIPMENT		X								
11				X	VERIFY PALLET/IGLOO AUX EQUIP--CCTV, INTERCOM, ETC		X								
12	600503			X	VERIFY GDB COMPATIBILITY WITH GDB UMBILICAL		X								
13	600504			X	VERIFY READINESS OF EXPMTS & SUP EQUIP FOR ACTIVATION			X							
14				X	ACTIVATE PALLET/IGLOO, CONTROL & DISPLAYS & SUP EQUIP			X							
15				X	VERIFY PERFORMANCE OF C&D CONSOLE DURING EXPERIMENT FUNCTIONAL TESTS			X							
16				X	VERIFY OPERATION OF PALLET-MOUNTED DEPLOYABLE EXPERIMENT EQUIPMENT			X							
17				X	VERIFY OPERATION OF EXPERIMENT/IGLOO MOUNTED MECHANICAL EQUIPMENT			X							
18				X	VERIFY FUNCT OPERATION OF EXPMTS/SUPPORT EQUIPMENT			X							
19				X	VERIFY DATA PROCESSING/RECORDING EQUIPMENT DURING EXPERIMENT CHECKOUT			X							
20	600504			X	CONDUCT EMI/RFI TESTS			X							
21	630508		X		CONDUCT PALLET/SS IGLOO ELECTRICAL BONDING TESTS AFTER PALLET/SS IGLOO MATING				X						
22	630508		X		CONDUCT & VERIFY PALLET/SS IGLOO ELECT/MECH INTERFACES				X						
23	630509		X		SERVICE & VERIFY COOLANT FLOW THROUGH GSE					X					
24			X		VERIFY ORBITER INTERFACE SIM OPERATIONAL CAPABILITY					X					
25			X		PERFORM PALLET/SS IGLOO BUS ISOLATION TESTS					X					
26			X		CONDUCT PALLET/SS IGLOO ELECT PWR DISTRIBUTION TESTS					X					
27			X		VERIFY PALLET/SS IGLOO CAUTION/WARNING CIRCUITRY					X					
28			X		CONDUCT SS IGLOO COMPUTER SELF-CHECKS					X					
29			X		VERIFY SS IGLOO IMS COMMAND/CONTROL & PERIPHERAL EQ					X					
30			X		VERIFY PALLET/SS IGLOO AUX EQUIP--CCTV, INTERCOM, ETC					X					
31			X		VERIFY SIG DISTR VIA SS IGLOO/ORBITER UMBILICAL					X					
32			X		VERIFY GDB OPERATION VIA THE GDB UMBILICAL					X					
33			X		CONDUCT FUNCTIONAL CHECKOUT OF IGLOO SUPPORT SYSTEM/EXPERIMENT EQUIPMENT INTERFACES					X					
34			X		CONDUCT EMISSIVITY TESTS OF PALLET/SS IGLOO EXTERNAL SURFACES					X					
35			X		CONDUCT SS IGLOO 24-HR PRESSURE DECAY LEAK CHECK					X					
36	630509		X		CONDUCT PALLET/SS IGLOO WEIGHT/BALANCE TEST					X					
37	660510	X			PERFORM PALLET/IGL/ORB PRE-INSTLN I/F VERIFICATION TESTS						X				
38		X			SERVICE PALLET/IGLOO WITH NON-HAZARDOUS FLUIDS AND LOW PRESSURE GASES						X				
39		X			VERIFY ORBITER READINESS TO ACCEPT PALLET/IGLOO						X				
40		X			PERFORM PALLET/IGLOO/ORBITER INTERFACE VERIFICATION TEST						X				
41		X			PERFORM ORBITER INTEGRATED TEST (OIT)						X				
42		X			CONDUCT ORBITER/PALLET/IGLOO EMC/RFI TESTS						X				
43	660510	X			PERFORM ORDNANCE INSTALLATION TESTS						X				
44	660511	X			CONDUCT FINAL PALLET/IGLOO PRELAUNCH TESTS							X			
45	660511	X			PERFORM PALLET/IGLOO HAZARDOUS MATERIALS LOAD TESTS							X			
46	600514			X	REFURBISH SUPPORT SYSTEMS IGLOO								X		
					A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM										
					B VERIFY OPERABILITY OF FLUID SYST COMPONENTS										
					C INSPECT/REPAIR ELECT CABLES/CONNECTORS AND FLUID LINES										
					D REFURBISH & VERIFY OPERATION OF IMS COMPONENTS										
					E. INSPECT/REPAIR SS IGLOO MATING SURFACES										
					F INSPECT/REPAIR SS IGLOO STRUCT STRESS/DAMAGE										
47	600516			X	REMOVE EXPMTS, CABLES, LINES & BRACKETS FROM P/IGLOO									X	
48	600518			X	REFURBISH/RECONFIGURE PALLET AND IGLOOS										X
					A DRAIN, FLUSH, DRY & CAP COOLANT SYSTEM										
					B VERIFY OPERABILITY OF FLUID SYST COMPONENTS										
					C VERIFY OPERABILITY OF PALLET/IGLOO POWER CONDITIONING SYSTEM										
					D INSPECT/REPAIR PALLET/IGLOO ELECTRICAL CABLES/CONNECTORS & FLUID LINES										
					E INSPECT/REPAIR PALLET/IGLOO MATING SURFACES										
					F INSPECT/REPAIR PALLET STRUCT STRESS/DAMAGE										

*NOTE THE FOLLOWING FUNCTIONAL FLOW BLOCKS INVOLVE SHIPPING, RECEIVING INSPECTIONS, MATING/DEMATING, INSTALLATION/REMOVAL, MISSION & POST-FLIGHT OPERATIONS WHICH DO NOT CONTAIN ANY TEST AND CHECKOUT REQUIREMENTS

1.0 EXPERIMENT SHIPMENT
5 0 GSE DISCONNECT
6 0 PALLET/IGLOO SHIPMENT
7 0 P/IGLOO & PSS EQUIP ARRIVAL & R/I
12 0 MISSION OPERATIONS (REF)
13 0 POSTFLIGHT OPERATIONS
15 0 PALLET/IGLOO SHIPMENT
17 0 EXPERIMENT SHIPMENT
19 0 POST-REFURB PALLET/IGLOO SHIPMENT

test requirements, are itemized in the footnote of the table. The guidelines and assumptions utilized in the development of this matrix are described in Section 4.1 of this volume.

TEST AND OPERATIONS RESPONSIBILITY ASSIGNMENTS

Responsibility criteria and assignment of tasks for test and operations activities are presented in the subsequent paragraphs.

Assignment Criteria

The assignment of personnel for the Spacelab program in the test and operations area was based upon the following criteria.

- Maximum involvement of the principal investigator (PI), his designee, and/or the payload specialists.
- Experiment discipline specialists (one for each technology area) will participate in the entire processing cycles of the equipment associated with their discipline.
- Each site maintains its own technician work force.
- Multi-skilled personnel will be chosen to the maximum possible extent.
- The same technicians that work on the flight hardware will perform GSE revalidation.
- In general, technicians will be resident personnel. Off-site support by this skill-level will be minimized.
- The site at which test and/or operation is conducted will have the primary responsibility for the accomplishment of the associated activities.

Task Responsibilities

The PI, his designee, and/or the payload specialists will be involved throughout the hardware processing cycle as consultants/participants for the experiment system tests for which they are responsible. The PI will have the final authority for the conduct of the testing which directly affects his experiment. The implementation of this authority, however, will be restricted to direction that does not compromise safety procedures or potentially cause damage to other experiment systems. The specific responsibilities of the PI are as follows.

- *Documentation.* Prepares documentation relevant to his experiments including environmental compatibility certification, safety compliance, and acceptance test results. Defines checkout procedures suitable for incorporation into an overall test and checkout procedure, and reviews/approves final proecedures and test results.

- *Specialized GSE.* Provides all special or experiment-unique GSE including development, qualification, maintenance, checkout, revalidation, and calibration.
- *Data Review.* Contributes information pertinent to assigned experiments for the preparation of installation, checkout, and transportation procedures.
- *Experiment Refurbishment.* Assures that experiments that are to be reflown have been refurbished to flight-readiness standards, including experiment-related equipment.

The experiment discipline specialists should have a working knowledge of the ATL experiment designs within their area of responsibility, and act as the interface between the PI and the test and operations personnel. In this way, a specialist may have the responsibility of coordinating the checkout activities of several experiments and, at the same time, be responsible to several PI's. The discipline specialists will follow their experiments throughout the processing cycle of the flight hardware.

The technician workforce will be (as a goal) comprised of multi-skilled personnel. Each site will maintain its own technicians. Local hiring will be the preferred method to reduce per-diem costs. During slack periods, the technicians can be utilized to perform related Spacelab activities such as GSE revalidation and maintenance.

The resident test engineers will be responsible for the orderly and timely accomplishment of all tests and operations at a given site. PI's, payload specialists, and test engineers from other sites where previous checkout activities occurred will participate in these test and operations activities.

5.0 INTEGRATOR INVOLVEMENT IN EXPERIMENT DEVELOPMENT

Throughout the development of the support functions and test and operations tasks associated with the integration and checkout of a Spacelab payload, the interrelationship between the PI and the payload integrator has been delineated. In this section, a summary of the payload integrator's role in experiment systems development is presented.

SUPPORT FUNCTION INVOLVEMENT

The non-recurring documentation effort provides the framework within which the PI will define/develop his experiment systems. The payload integrator must provide Spacelab and Orbiter payload accommodations handbooks to the PI's. In addition, the integrators should provide a design handbook that delineates allowable materials, weights, cables, mounts, etc., and preferred assembly, test, handling, and checkout procedures. Safety and instrumentation/data processing guidelines should also be included. Software development guidelines should reflect the capability/capacity of the Spacelab data management system.

PI mission planning and mission operations tasks can be significantly simplified if the integrator provides various software *tools*. These tools should be the same as those the integrator will use in combining all the experiment systems operations of a given payload. For example, the computer program to derive the total crew mission timeline should be provided to the PI to develop the crew timeline for an individual experiment.

Configuration control is the responsibility of the integrator--not the PI. The integrator will perform this service throughout the development phase. Included in this service is the identification of appropriate common payload support equipment.

Hardware integration will require the allocation of space and wiring to accommodate several experiment systems. The payload integrator will design and fabricate the required cables and mounting brackets that are not specifically related to the experiment system design. Where appropriate, the integrator will provide these cables/mounts to the PI for Level IV integration (PI acceptance tests).

One of the most important services that the payload integrator could provide to the PI is standardized identification of experiment system requirements. The integrator has the visibility to establish the required depth and breadth of data to combine multiple experiment systems. By providing standard formats for identification of requirements such as measurements, command/control, telemetry, ground truth, trajectory, lighting, data processing, power, cooling, display, recording, etc., the task of the PI can be simplified. The PI will know specifically what data the integrator requires. Both multiple iterations and over-stipulation of requirements can be avoided.

TEST AND OPERATIONS INVOLVEMENT

As the integrator is responsible for interfacing cables and mounts, it would be advisable to have integrator test personnel participate in Level IV integration activities. This participation would facilitate the incorporation of any required change in the flight hardware.

Environmental compatibility certification is probably the primary role of the payload integrator in experiment systems development. Based upon data from previous flights the integrator can, with proper analysis techniques, minimize the environmental qualification testing of experiment equipments. Utilization of verified environmental models coupled with actual flight data on previously flown experiment equipments will provide the payload integrator with the visibility to recommend to the PI the most efficient technique for environmental certification. The integrator may alleviate a potential environmental problem by recommending shock/vibration/acoustic mounts or devices that could also negate equipment qualification testing.

INVOLVEMENT SUMMARY

Except for safety considerations, the previously identified activities of the payload integrator during experiment development are not mandatory. However, all the activities are recommended and were incorporated in the definitization of the candidate processing concepts. It is believed that these payload integrator activities will simplify the tasks of the PI's, reduce the costs of development of experiment systems, and facilitate the integration and checkout of multiple experiment systems.